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# DELTA SALINITY STUDY
## 1978-1979 PROGRESS REPORT


BY

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## PREFACE

Recent work on salinity in the Delta (Meyer and Carlton 1973, 1974, 1975 and Meyer, Carlton, Kegal and Ayers, 1976) along with the SWRCB hearings leading to 1978 Decision 1485 demonstrated the need for a better understanding of the movement of salt and water under conditions of sub-irrigation as practiced in the Delta. This includes factors affecting the relationship between irrigation water quality and the resultant soil salinity (and, by extension, crop response). One of the factors affecting this relationship is the extent to which poorer quality groundwaters move up during an irrigation to provide some of the water used by the growing crop. Work on this problem was begun in 1977 by Carlton, Hanson, and Meyer. However, the studies were conducted on only one island and it was not known to what extent the results were valid on other islands with different soil characteristics. Furthermore, it became apparent that the effectiveness and efficiency of winter leaching was a very important factor in the relationship between irrigation water quality and soil salinity and that very little was known about this process under Delta conditions.

As a result, this current two year study was begun to improve our knowledge on salt and water movement under sub-irrigation on a variety of soil types in the Delta. Studies on the leaching process were included in order to understand water and salt movement during leaching under various conditions in the Delta and to attempt to quantify the leaching process. With a clearer understanding of the fundamental processes involved, it is hoped that improved methods of leaching can be developed. This report is a first year progress report on this two year study and hence there are still many "loose ends" so discussions are short and conclusions can be considered only tentative.

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## BACKGROUND

Good water quality in the Sacramento-San Joaquin Delta is necessary for the preservation of the agricultural industry in the Delta, among other reasons. Water quality in the Delta is controlled by fresh water outflows into the bay. The better the water quality in the Delta, the larger the ✓ outflow required to minimize sea-water intrusion.

Questions have been raised concerning the water quality necessary to maintain Delta agriculture. Studies have been made to help answer these questions and water quality objectives, based on information obtained from these studies, have been established. However, vital information concerning relationships between crop yield, soil salinity, and irrigation water quality under Delta conditions is still not available.

Numerous studies on the relationship between crop yield and soil salinity have been conducted in well-drained, mineral soils (Ayers, 1977). Under well-drained conditions, it is assumed that the source of salts in the soil is primarily from the irrigation water. This assumption allows them to establish a relationship between crop yield and irrigation water quality provided some defined leaching of the soil occurs.

However, no information is available on the relationship between crop yield and soil salinity for organic soil under high water table conditions such as exist in the Sacramento-San Joaquin Delta. A study is currently being conducted by the U.S. Salinity Laboratory and the University of California Cooperative Extension to better define crop yield-soil salinity relationships under well-drained conditions and also to determine the effect of a high water table on this relationship.

Because of the subsurface irrigation method used in the Delta, relationships between irrigation water quality and soil salinity are more complex than those under surface-irrigated soils. One problem is a potential displacement of groundwater by irrigation water percolating from the spud ditches. This displacement process could result in groundwater replenishing the root-zone moisture supply. The quality of the groundwater is usually worse than that of the surface water. Thus soil salinity may depend on the groundwater quality if this displacement process does occur.

Under subsurface irrigation, water flows upward into the root zone. Since normal downward leaching does not occur during irrigation, salts accumulate in the root zone. Salt removal occurs only during periodic leaching of the soil (usually during the winter). The amount of salts removed depends on the efficiency of the leaching process. Thus, the salinity of the soil in the root zone depends not only on the quality of the water replenishing the root zone moisture supply but also on the effectiveness of any periodic leaching to carry away the accumulated salts. Therefore in order to arrive at a clear understanding of the relation of irrigation water quality to the root zone salinity, it is as important to understand the leaching process and to be able to quantify it as it is to understand the irrigation process.

The purpose of this two year project is to investigate factors affecting soil salinity under Delta conditions. This is a progress report of the results obtained during the first year of the project.

## SUMMER IRRIGATION STUDIES

Previous work on MacDonald Island in 1977 revealed that lateral movement of irrigation water occurred during irrigation. The contributing factor for this movement was a peculiar mineral layer of silt-loam texture 2-2 1/2 feet below the surface. The apparent low permeability of this layer prevented significant vertical flow beneath the spud ditch. Thus little groundwater displacement occurred. It was concluded that the irrigation water replenished the root zone.

Observations by farm advisors and others indicated that this mineral layer was not typical of Delta soil profiles. Therefore sites for 1978 experiments were selected which did not contain the type of layer such as existed on MacDonald Island. Sites were located on Rindge Tract, Bouldin Island, and Venice Island.

The method used to determine subsurface water movement was to establish a grid system of piezometers between two spud ditches (see Appendix). Both positive and negative water pressures could be measured with these instruments. The hydraulic head was calculated for each node of the grid system using this piezometer data. Since water flows in the direction of decreasing hydraulic head, comparing the values of hydraulic head for all points in the grid system provided information on the subsurface water movement. A similar grid system of water quality probes was also installed.

Rindge Tract

Soil Profile Description. The soil profile at Rindge Tract consisted primarily of a peaty muck. The depth of the organic soil profile was about five feet although a thin layer of brown mineral material occurred between four and five feet deep. Beneath the peat layer, the so-called "blue clay" was found, although for this case, the material was more of a compacted sand. Large cracks in the top two to three feet of the profile were observed in the soil.

Subsurface Water Movement. Subsurface water movement prior and during irrigation is shown in Figures 1-3. Prior to irrigation, the water table was between the four and five foot depths. The flow pattern (Figure 1) indicated that subsurface water was flowing upward from the water table. This upward movement was in response to evapotranspiration.

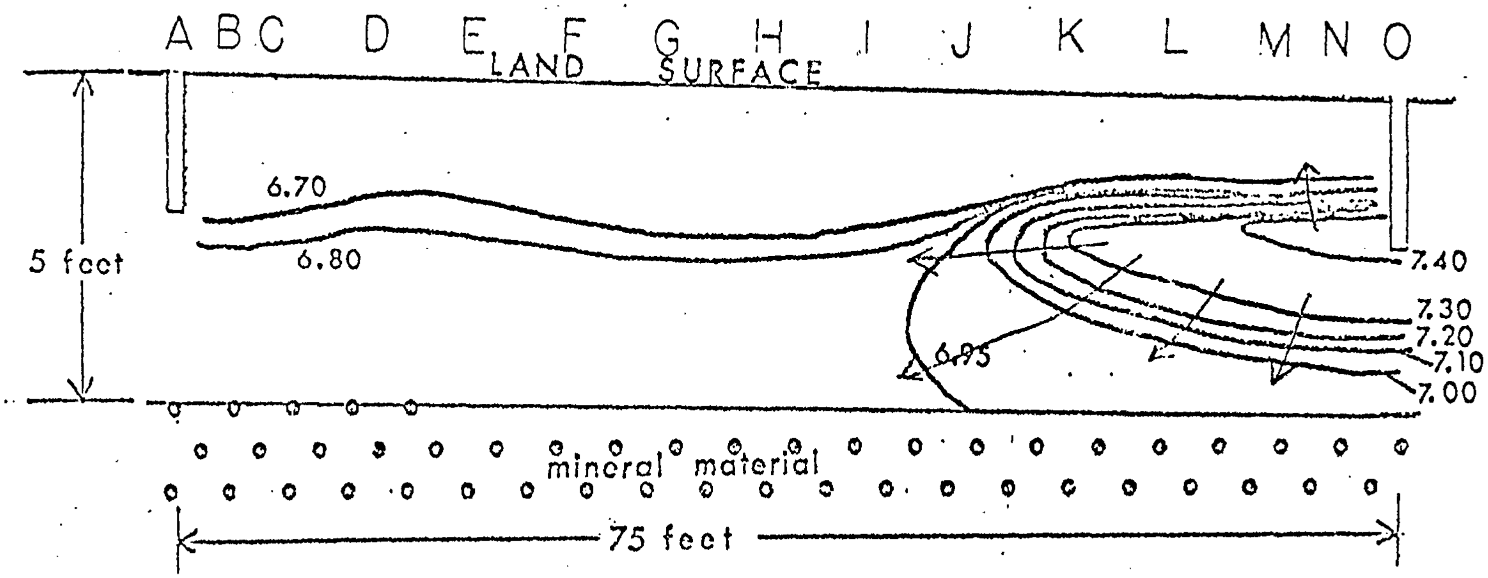


FIGURE 2. LINES OF EQUAL HYDRAULIC HEAD (METERS) 45 MINUTES AFTER START OF IRRIGATION- RINDGE TRACT.

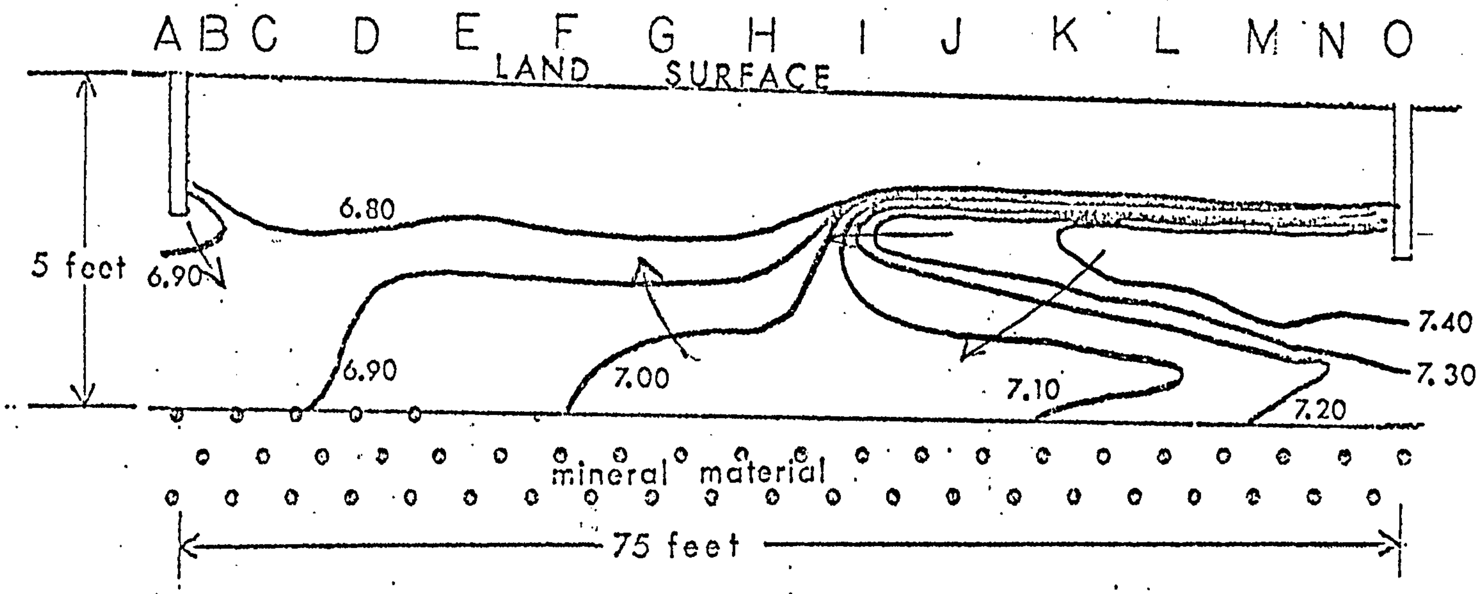


FIGURE 3A. LINES OF EQUAL HYDRAULIC HEAD (METERS) TWO HOURS AFTER START OF IRRIGATION- RINDGE TRACT.

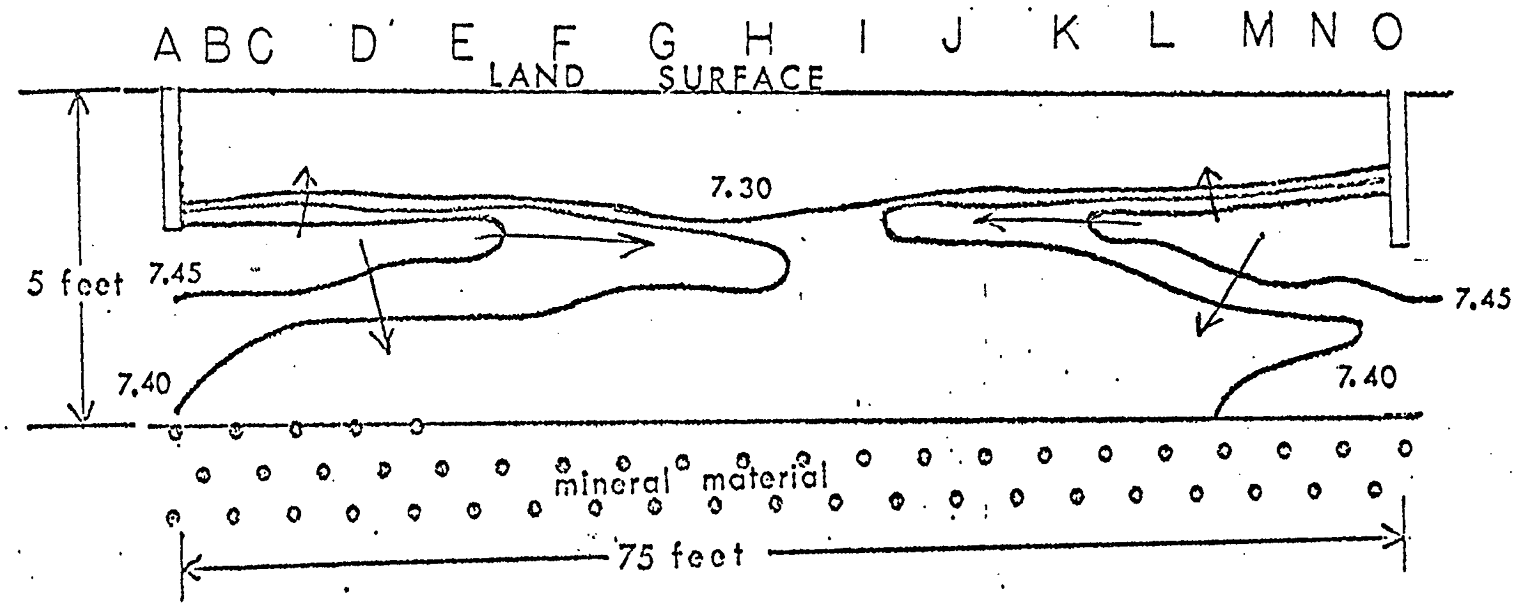


FIGURE 3B. LINES OF EQUAL HYDRAULIC HEAD (METERS) 4 HOURS AFTER START OF IRRIGATION- RINDGE TRACT.

The irrigation water arrived first at the "O" spud ditch (the water arrived at the "A" spud ditch about 1 1/2 hours later). Upon arrival at "O" lateral water movement from the ditch was considerably faster than vertical movement (Figure 2). After 30 minutes of irrigating, the change in hydraulic head (which results from water flowing from 0) at L2 (about 12 feet from the spud ditch at two-foot depth) was nearly twice as much as that at 03 (one foot below the spud ditch). Also, the hydraulic head at L2 was greater than that at 03. (Prior to the irrigation the situation was reversed). These comparisons show the rapid rate of lateral flow compared to vertical flow. A similar flow pattern developed when the water arrived at the "A" spud ditch.

After about 1 1/2 hours had elapsed, (Figure 3a) the wetting front resulting from flow from the "O" spud ditch had advanced approximately one half the distance (35 feet) between the spud ditches. Beyond the wetting front advance, the water table had risen slightly. The flow pattern indicated that upward flow was occurring beneath the water table between A-H. This upward flow indicates that some displacement of the subsurface water by the irrigation water may have occurred between A through H.

When the maximum water table height had been reached, water flow below two feet was downward (Figure 3b). Thus, it appears that any subsurface water originally displaced upward by the irrigation water was displaced a second time but downward.

It is believed that, based upon these flow patterns, displaced subsurface water was not involved in replenishing root zone. The water replenishing the root zone was the irrigation water.

The contributing factor for the lateral movement is believed to be a system of cracks and fissues in the upper 2-3 feet of the profile. These somewhat surprising in view of the rapid movement of water through the profile. Reasons for this behavior are unknown at this time.

Soil Salinity. The soil salinity profile, obtained from chemical analysis of saturation extracts of soil samples are shown in Table 2 for one sampling location.

Table 2. Chemical Constituents of Saturation Extracts of Composite Sample B, Rindge Tract, June, 1978.

These values are typical of those throughout the water quality sampling grid.

An analysis of the data obtained throughout the duration of the experiment revealed no significant changes in water quality of the subsurface water with time even at locations next to spud ditches. This result is cracks were discovered during soil sampling and were large enough to insert one's hand. It is believed that water movement through these cracks is more like "pipe" flow than flow through a porous media which results in an "apparent" hydraulic conductivity of the upper part of the profile that is much higher than the hydraulic conductivity of the soil profile below the system of cracks and fissures. This difference in hydraulic conductivity is believed to be responsible for the rapid lateral movement.

Upon discovering this rapid horizontal movement, conversation with the cooperator brought out his observation that the entire tier of fields of which our plot was a part "subbed" very rapidly and normally required only about a day to irrigate. However, he had many fields where this rapid movement did not take place and required five times longer to irrigate. It was decided that these latter fields must be studied in summer 1979 in order to complete the picture.

Subsurface Water Quality. The subsurface water quality profile at B is shown in Table 1 for July 21, 1978 (two days after irrigation).

Table 1. Chemical Analysis of Subsurface Water Quality for July 21, 1978 at "B" Set of Water Quality Probes, Ringde Tract.

a comparison of the subsurface water quality data with the saturation extract data indicate that values of the chemical consituents of the extract are considerably higher than those of the water quality samples. This result was not expected since theoretically the saturated soil extract should contain about the same quantity of salts as that extract from below the water table by the soil probe, on perhaps even less. We have no certain explanation for this phenomenon, but feel it may have an important bearing on the salt movement process. We expect to explore this further in the second year of the project.

The differences in the sulfate profiles between the soil analyses (Table 2) and subsurface water quality from probes (Table 1) requires some explanation. Not only was there more sulfate in the soil saturation extracts than in the soil water extracted by probes, the profiles were the reverse of one another, i.e. whereas the soil analyses showed measuring sulfate with depth, the probe-extracted soil water showed decreasing sulfate with depth, in fact there was no detectable sulfate in the water from soil probes at the 4 and 5 feet depths. The soil samples were taken in the late spring shortly before the first irrigation and were above the then existing water table. Standard procedures for preparing soil samples for analysis include slow drying in open bags prior to analysis. On the other hand, all probe samples were extracted from the field soil at points below the water table and capped and protected from air after sampling. Thus, the soil samples were not anaerobic and any mineralized sulfur compounds had the opportunity to be fully oxidized to the sulfate level. By comparison, the water table water, surrounded by decomposable organic matter, quickly becomes anaerobic and can reduce any sulfate present to insoluble sulfides or volatile $H_2S$ gas. Just how to deal with this fickle nature of inorganic sulfur compounds is not clear but the considerable content of sulfate in many if not most of the Delta soils requies more attention than has been given in the past if we are to fully understand the salt problem.

A comparison of the June and October soil salinity data (Figure 4) reveals that a slight increase in soil salinity occurred in top 8" to a foot of the soil profile. This increase is due to evapotranspiration. Below this depth, soil salinity decreased indicating removal of salt during the irrigation.

Bouldin Island.

Soil Profile. Data describing the soil profile at the Bouldin Island site is listed in Table 3.





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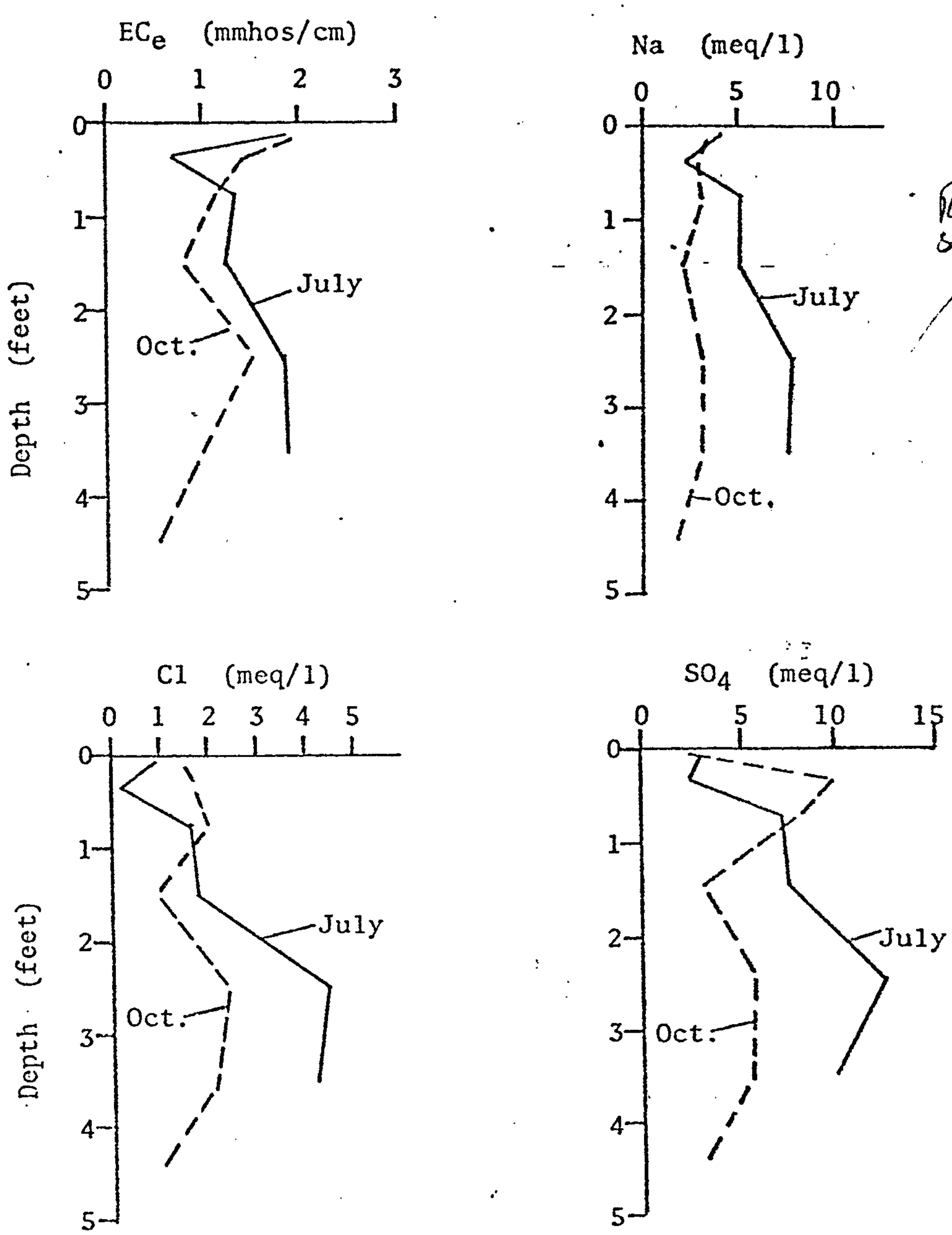


Rindge, water table about 4 ft.

Figure 4. Changes in soil salinity with time- Rindge Tract.

Table 3. Description of Soil Profile at Bouldin Island Site.

| Depth (feet) | Material |
|---|---|
| 0-1 | Top layer of muck |
| 1-5 | Brown peat with small fibers |
| 5-6 | Muck |
| 6-7 | Muck, increasing mineral content |
| >7 | Mineral material similar to a sandy loam. (Depth of material is at least to nine feet). |

<u>Subsurface Water Movement.</u> Flow patterns of subsurface water movement are shown in Figures 5-9.

Prior to the irrigation, flow was primarily in the upward direction (Figure 5). Above the water table, this upward movement was due to evapotranspiration as was the case for Rindge Tract. Below the water table, the upward movement is believed to be caused by an artesian condition. Evidence for this condition can be seen from the flow pattern since the largest hydraulic head at this time occurred at the six to eight foot depth between locations G-K. Further evidence of artesian flow is found from the chemical analyse of the subsurface water, which is discussed later.

At the beginning of the irrigation, rapid lateral movement of water (between the 2-3 depth) occurred. Vertical downward flow from the spud ditch appeared to be slow (Figure 6). Water flow from the spud ditches continued to be primarily horizontal throughout the duration of the irrigation (Figures 7,8).

The reason for this lateral movement is believed to be a system of cracks and fissures in between 2-4 feet below the surface similar to that at Rindge Tract. These large "pore" spaces result in a high apparent hydraulic conductivity compared to that of the underlying material. This difference is the contributing factor for the horizontal movement.

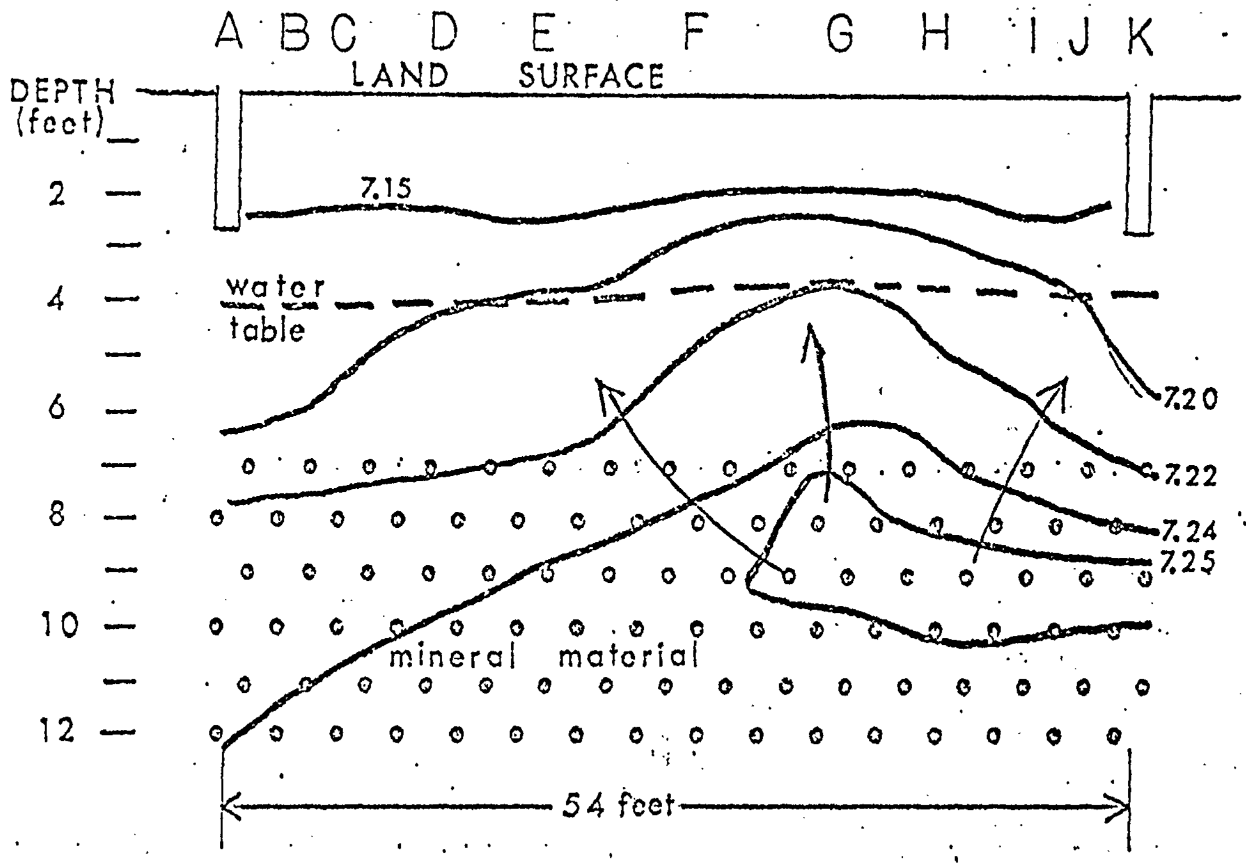


FIGURE 5. LINES OF EQUAL HYDRAULIC HEAD (METERS) PRIOR TO IRRIGATION-BOULDIN ISLAND.





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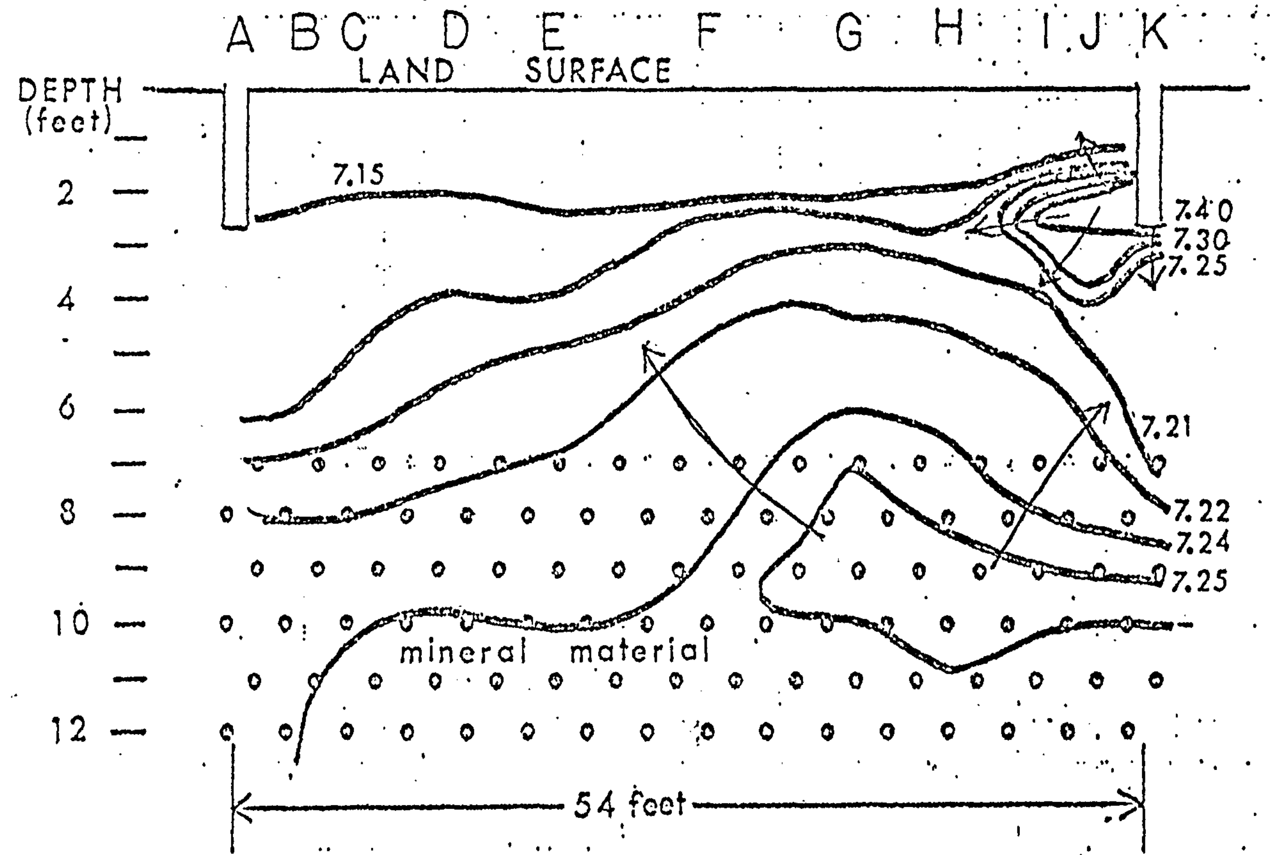


FIGURE 6. LINES OF EQUAL HYDRAULIC HEAD (METERS) 15 MINUTES AFTER START OF IRRIGATION- BOULDIN ISLAND.





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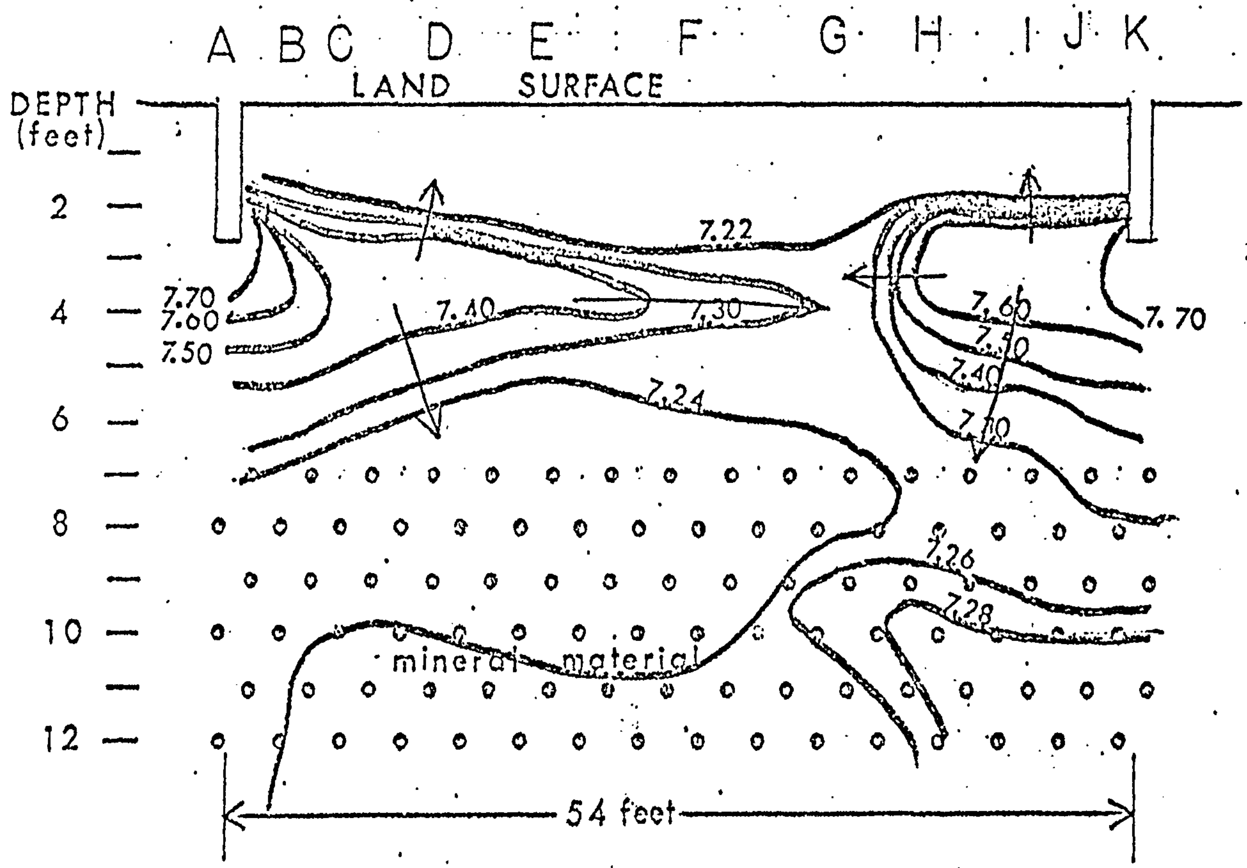


FIGURE 7. LINES OF EQUAL HYDRAULIC HEAD (METERS) 150 MINUTES AFTER START OF IRRIGATION- BOULDIN ISLAND.





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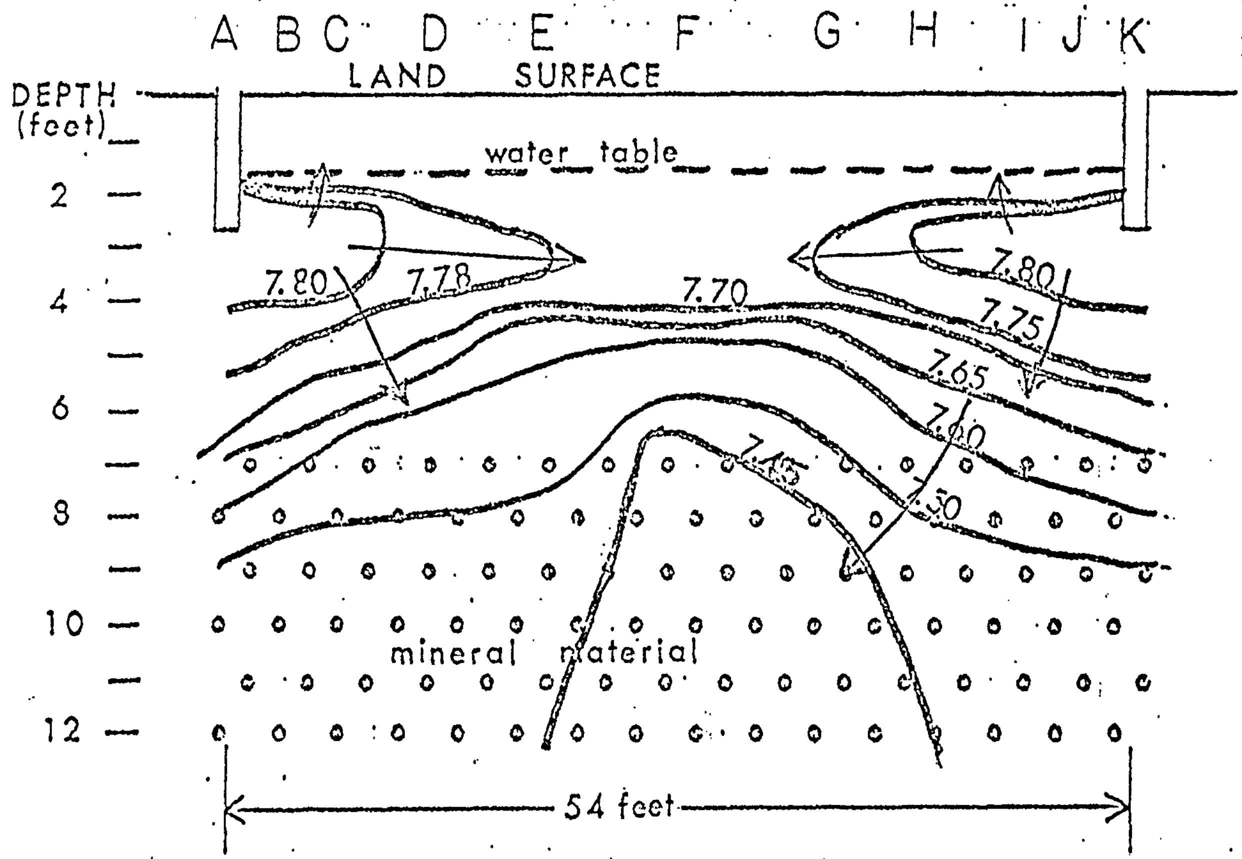


FIGURE 8. LINES OF EQUAL HYDRAULIC HEAD (METERS) ABOUT 12 HOURS AFTER START OF IRRIGATION- BOURLDIN ISLAND.

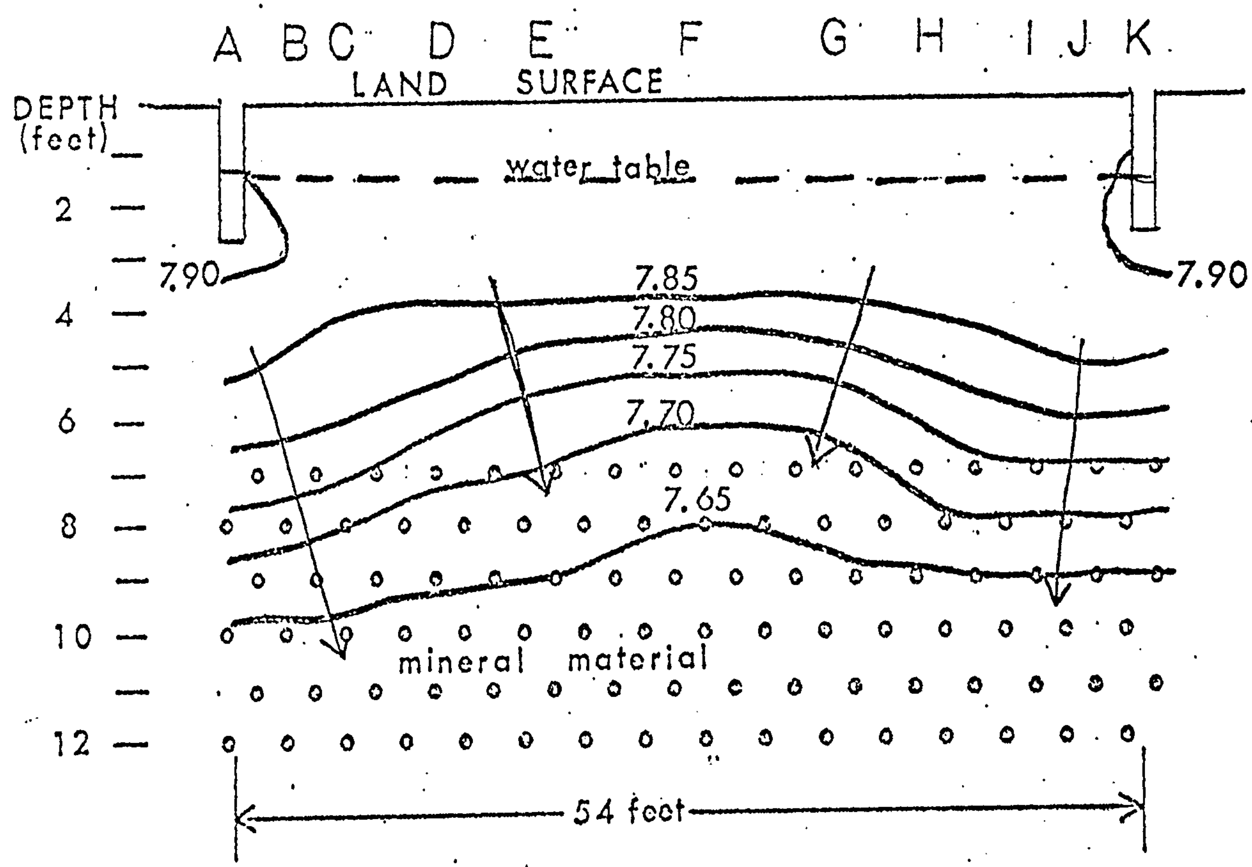


FIGURE 9. LINES OF EQUAL HYDRAULIC HEAD (METERS) ABOUT 24 HOURS AFTER START OF IRRIGATION- BOULDIN ISLAND.

Once the irrigation ceased, the flow pattern shown in Figure 9 developed. This pattern indicated that static conditions (no subsurface water movement existed at depths between one to three feet. However at depths below three feet, the flow pattern shows downward movement of subsurface water.

The principle of continuity requires that under saturated conditions, inflow into a given volume of a soil profile must equal outflow unless changes in the bulk density of the soil occur. However, this flow pattern shows no flow above three feet (water table was near the one-foot depth) and downward flow below three feet, which appears to violate this principle. No significant changes in bulk density are believed to have occurred.

A possible (and probable) explanation for this phenomenon is that due to the system of cracks between two to three feet (with the resulting high apparent hydraulic conductivity) and slow subsurface water movement that is believed to exist at that time, hydraulic head losses in this part of the profile were very small and could not be determined by the mercury piezometers. However, since no cracks are believed to exist below the three foot depth, the hydraulic conductivity of the soil is smaller than that above three feet, thus hydraulic head losses were greater even though flow rates were small and differences in hydraulic head could be measured by the piezometers. Thus it is believed that the source of the subsurface water moving downward below the four foot depth is the water in the upper part of the profile and that continuity with regard to water movement is maintained.

It has been noted that in Figure 5, the flow pattern shows a source of subsurface water at H-K at depths of six to eight feet. At the end of the irrigation, a sink for the water developed in this area of the profile.

In-situ measurements of hydraulic conductivity were made using the auger hole method (Kirkham, 1971). The range of hydraulic conductivities was between 0.11 meters/day and 0.34 meters/day, the average was 0.20 meters/day at depths above 5 feet. One measurement, not included in the above data, was ≈ 30 meters/day. This auger hole intersected a crack in the soil, thus preventing accurate measurements. This value would reflect the "apparent" hydraulic conductivity of the soil. With the one exception, these values are somewhat similar to those of a sandy loam or silty loam soil.

Subsurface Water Quality. The subsurface water quality profile at location F is shown in Table 4. The EC, Cl, and $Na^+$ increased with depth down to a depth of six feet and then decreased slightly. Sulfate generally decreased with depth. Sulfate concentration was negligible at locations A-F below 6 feet, but was significant at locations H-K at these depths (Table 5). An explanation for this difference may be found in the flow pattern shown in Figure 5 which shows a source of subsurface water at H-K at depths of six to eight feet. If this water is a sulfate water flowing through a nonorganic aquifer, then differences in sulfate concentration at these depths can exist, which is the case at this site. However, the source of this subsurface water is unknown, but is believed not be flowing directly from the river.

Changes in chemical constituents with time were insignificant.

Soil Salinity. The soil salinity profile for F sampling site is shown in Table 6. Data from other sampling sites is similar. Analysis of the data indicates that between July and October, salts accumulated in the first foot of soil, but below one foot, salts were leached out of the profile (Figure 10). This is similar to what happened at Rindge Tract and the discussion on partial leaching during irrigation is pertinent to the Bouldin plot as well.

Table 4. Subsurface Water Quality Profile at "F" on August 3, 1978, Bouldin Island.

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| Depth (feet) | EC mmhos/cm | Cl meq/l | Na meq/l | $SO_4$ meq/l |
|---|---|---|---|---|
| 2 | 2.37 | 8.0 | 10.0 | 9.7 |
| 3 | 2.55 | 8.0 | 12.6 | 7.9 |
| 4 | 2.74 | 10.8 | 17.0 | 7.8 |
| 5 | 3.08 | 14.4 | 19.1 | 7.4 |
| 6 | 3.30 | 15.5 | 19.8 | 2.2 |
| 8 | 3.13 | 15.9 | 16.5 | 0.4 |
| 10 | 3.11 | 15.4 | 15.2 | 0.6 |

below static water table

Table 5. Sulfate profile, August 3, 1978, Bouldin Island. (Concentrations are in meq/l).

| Depth (feet) | Location | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | D | F | H | J | K |
| 2 | - | 15.4 | 3.4 | 9.7 | 6.7 | 10.8 | - |
| 3 | 11.8 | 8.1 | 9.2 | 7.9 | 7.3 | 9.4 | 7.9 |
| 4 | 10.6 | 8.7 | 6.7 | 7.8 | 11.4 | 11.1 | 9.1 |
| 5 | 9.0 | 5.8 | 6.8 | 7.4 | 12.0 | 13.0 | 10.3 |
| 6 | 5.4 | 1.2 | 3.4 | 2.2 | 13.0 | 12.3 | 11.9 |
| 8 | <0.1 | <0.1 | <0.1 | 0.4 | 8.5 | 10.5 | 10.9 |
| 10 | <0.1 | <0.1 | <0.1 | 0.6 | 6.0 | 4.6 | 8.4 |

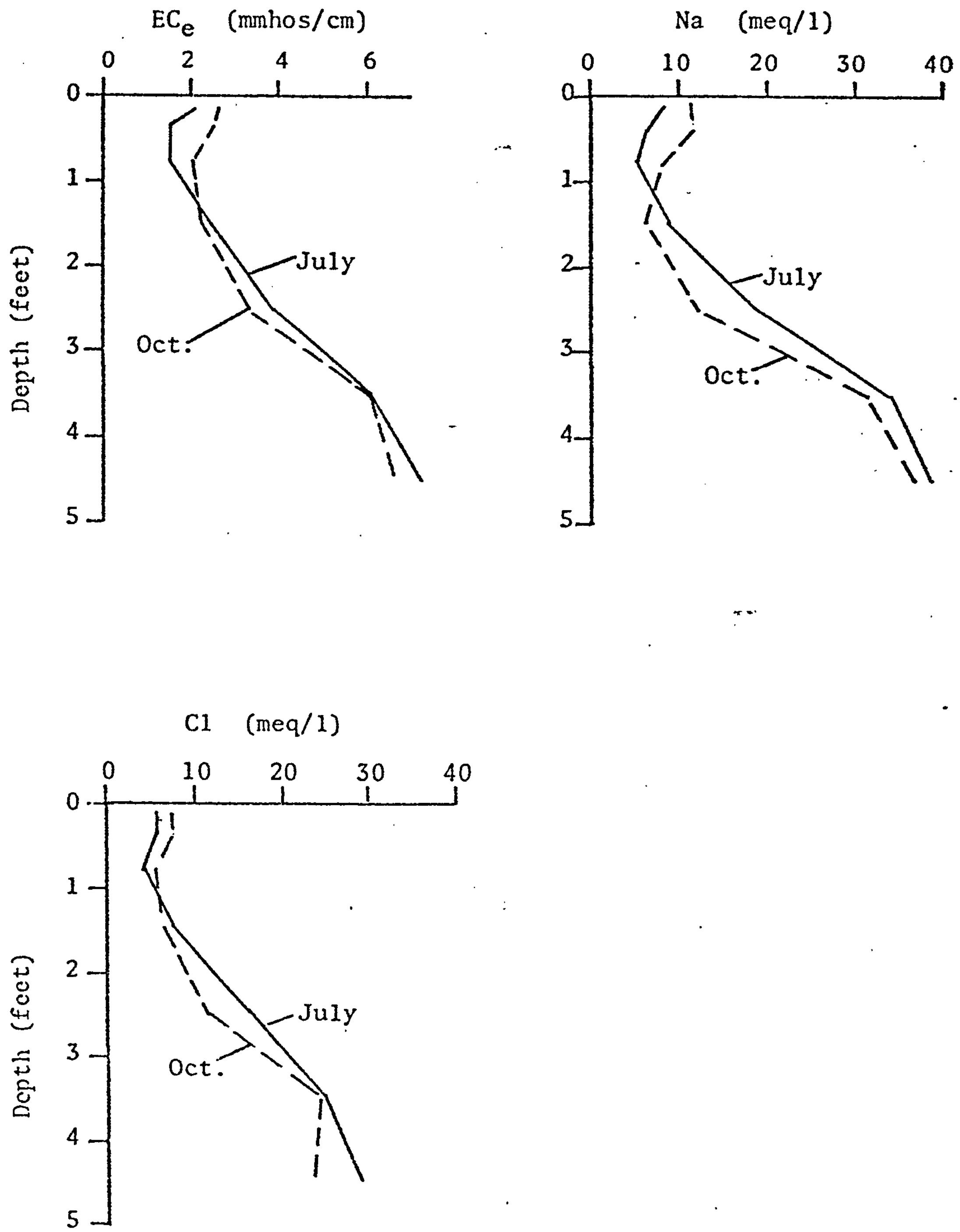


Figure 10. Changes in soil salinity with time- Bouldin Island.

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Table 6. Soil Salinity Profile at "F", Bouldin Island.

| Depth Interval (feet) | ECe mmhos/cm | Ca+Mg meq/l | Na meq/l | Cl meq/l | $SO_4$ meq/l |
|---|---|---|---|---|---|
| 0-0.25 | 2.64 | 22.6 | 11.5 | 7.9 | 10.9 |
| 0.25-0.50 | 2.50 | 21.0 | 9.8 | 7.2 | 7.6 |
| 0.5-1 | 2.04 | 14.6 | 8.9 | 6.7 | 5.0 |
| 1-2 | 2.26 | 14.0 | 10.6 | 8.2 | 7.5 |
| 2-3 | 3.30 | 21.8 | 18.5 | 13.6 | 12.4 |
| 3-4 | 6.08 | 40.2 | 37.6 | 25.5 | 28.0 |
| 4-5 | 6.35 | 37.8 | 42.0 | 30.9 | 25.0 |

## Venice Island

Soil Profile. The Venice Island site was chosen because of its contrast with Rindge and Bouldin in that it has a deep profile of apparently previous raw peat or "buckskin" capped with a relatively shallow layer of muck which was not as well-decomposed as on the Rindge and Bouldin sites. As a result, the piezometer grid went to 12 feet which is the depth of the peat profile.

Subsurface Water Movement. Analyses of data on subsurface water movement at the Venice Island site seems to indicate similar water movement from the spud ditches as occurred at Rindge Tract and Bouldin Island. However, at Venice Island, the initial water table depth was small compared to those at the other sites, thus initial head differences between the subsurface water and the irrigation water in the spud ditch were small. As a result, water flow from the spud ditch was small and well-defined flow patterns were generally not obtained. Figure 11 is one of the few flow patterns from which a trend can be seen.

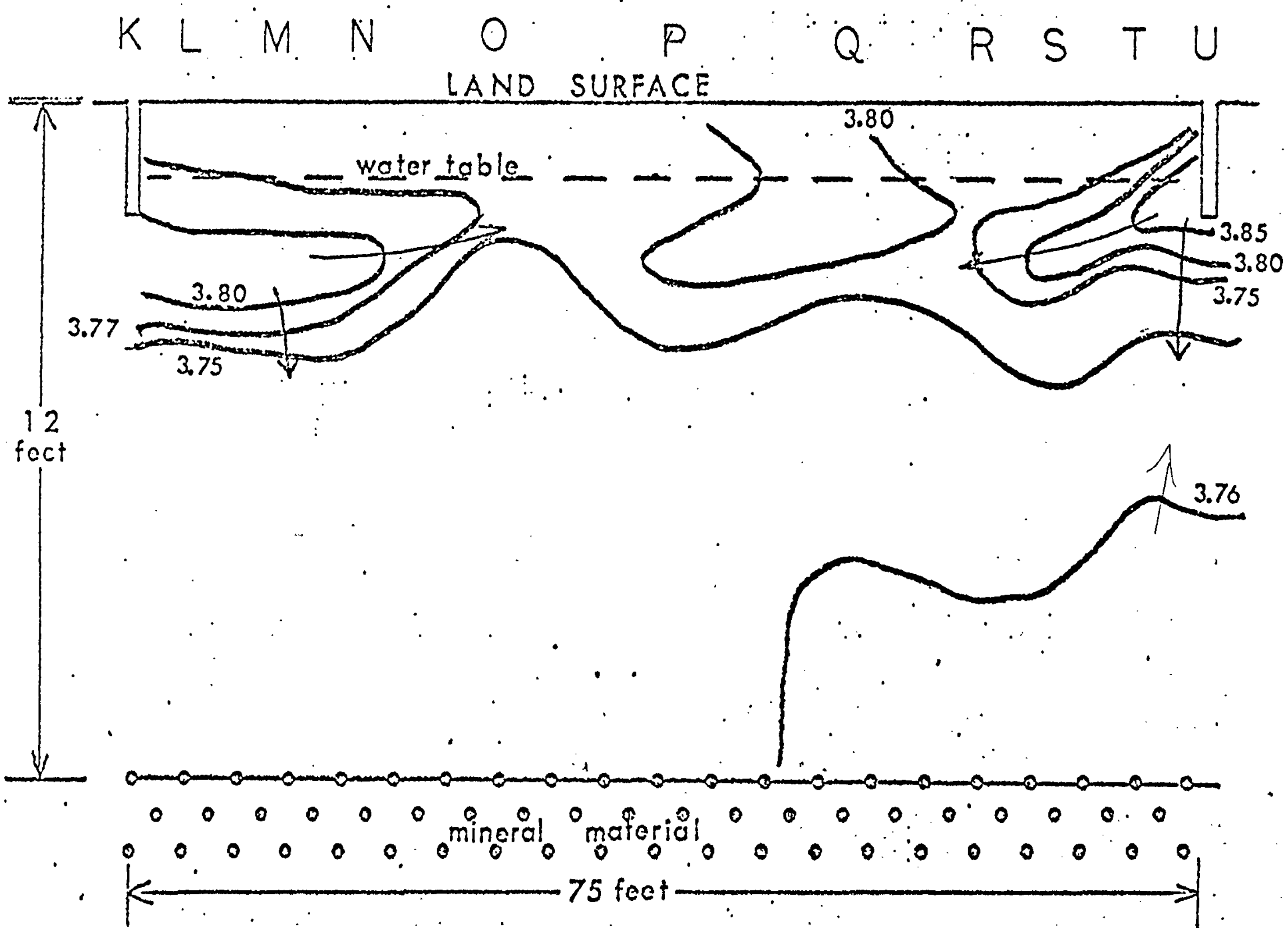



FIGURE 11. LINES OF EQUAL HYDRAULIC HEAD (METERS) 18 HOURS AFTER START OF IRRIGATION- VENICE ISLAND.

Although well-defined patterns were not consistently obtained, it is believed that subsurface water movement from the spud ditches ~~is~~ primarily horizontal. This is again due to cracks and fissures observed in the soil which import a high 'apparent" hydraulic conductivity to the top 2-4 feet of soil.

Subsurface Water Quality. A subsurface water quality profile is shown in Table 7. The total dissolved salts in profile was low reflected by low EC values) throughout the profile. EC values generally decreased with increasing depth. However, a slight increase sometimes occurred at the 12-foot depth. Profiles of chemical constituents of the water were similar to that of EC except for bicarbonate. The "bicarbonate" titration is of dubious value, except to assist in balancing the anions and cations since the method partially titrates any weak organic acid in the solution as well. The low or nil values for sulfate at the deeper depths was discussed earlier under the Rindge Tract experiments.

Table 7. Subsurface Water Quality Data at P. Venice Island, on July 25, 1978.

| Depth (feet) | EC (mmhos/cm) | Na (meq/l) | Ca+Mg (meq/l) | Cl (meq/l) | $SO_4$ (meq/l) | $HCO_3$ (meq/l) |
|---|---|---|---|---|---|---|
| 2 | 3.22 | 7.1 | - | 5.0 | 34.0 | - |
| 3 | 1.89 | 3.2 | 20.1 | 2.0 | 15.6 | 6.3 |
| 4 | 1.32 | 1.6 | 13.3 | 1.1 | 5.7 | 7.6 |
| 5 | 0.90 | 1.1 | 8.2 | 0.6 | <0.1 | 9.2 |
| 6 | 0.90 | 1.0 | 4.8 | 0.6 | <0.1 | 6.2 |
| 8 | 0.75 | 1.0 | 6.1 | 0.3 | <0.1 | 5.8 |
| 10 | 0.75 | 1.0 | 6.3 | 0.8 | <0.1 | 6.3 |
| 12 | 0.81 | 1.0 | 6.3 | 1.0 | <0.1 | 7.1 |

Of particular interest is water quality changes with time beneath the spud ditch at "K" and at "L", (Figure 12). At the start of the irrigation, the EC was high at K3 but it decreased as the irrigation proceeded until day 8, indicating a leaching by the irrigation water immediately under the spud ditch. (After day 8, EC at K3 increased with time). At K4, however, there was only a slight decrease in EC during the irrigation. The differences in changes in EC at the two depths may indicate that vertical movement of water beneath the spud ditch is small below 3-4 feet.

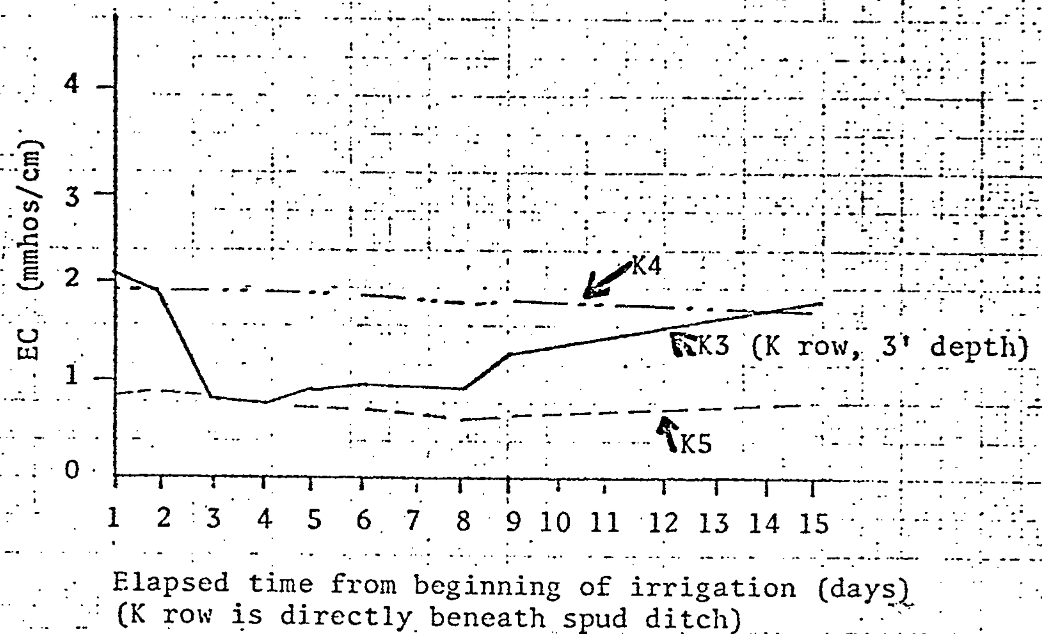
At location L (adjacent to the spud ditch), large changes in EC with time occurred at L2, smaller changes occurred at L3, and still smaller changes at L4. This behavior indicates that water movement from the spud ditches is largely horizontal and that vertical movement is slow compared to horizontal movement, again reinforcing other data that the main source of water to the root zone during irrigation is horizontally directly from the applied irrigation water and not displaced groundwater moving upward.

Soil Salinity. The soil salinity profile is illustrated in Figure 13. The data shows salt accumulation in about the top six inches and salt removal at depths between 0.5 to 3-4 feet, essentially the same pattern as at Rindge and Bouldin, and discussed earlier.

## WINTER LEACHING STUDIES

### Leaching Trial-Empire Tract

Piezometers and subsurface water quality probes were installed at a location on Empire Tract to determine the effectiveness of leaching under Delta conditions. The leaching process was accomplished by both rainfall and flooding the field with river water. Dikes or beams along the field edge,



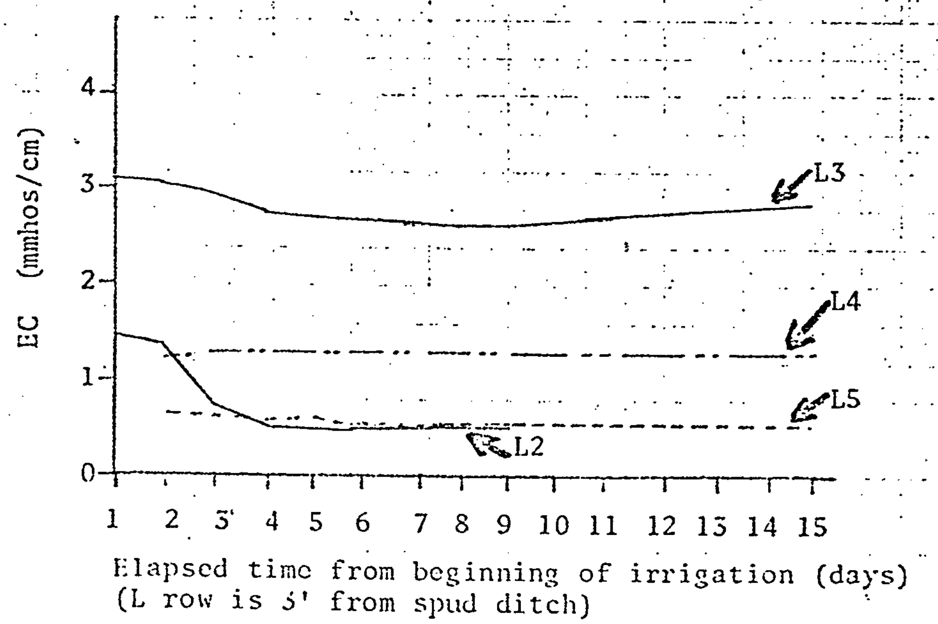




Figure 12. Changes in subsurface water quality with time during irrigation- Venice Island.

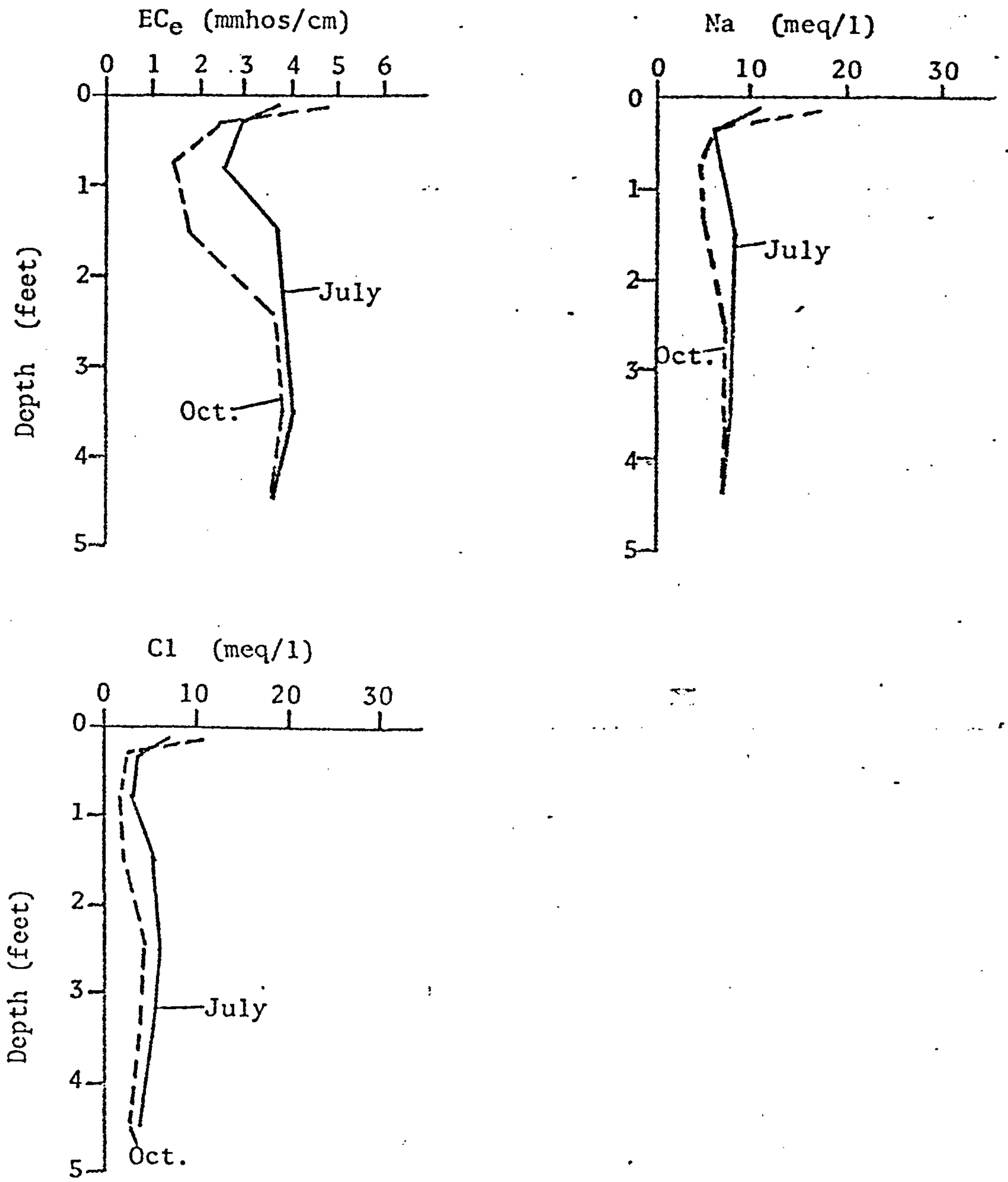



Figure 13. Changes in soil salinity with time- Venice Island

next to the 4' drain ditch allowed each field to be flooded while the drains remain open and operating.

The lower end of each field had two additional "V" ditch drains installed which were protected from the flooded field by their own berm. These "V" ditches were 1 1/2 feet below the normal soil level and drained into the normal operating drainage system at the lower end of the fields.

Two sites were chosen in the same field. One site was next to a main drain; the other was next to a four-foot drain. Hydraulic head data from a grid system of piezometers provided information on the flow pattern. Sub-surface water samples obtained from a grid system of water quality sampling probes provided information on salt movement. Soil samples before and after the flooding indicated the degree of leaching accomplished.

Figure 14 shows changes in water pressure head with time for the duration of the trial (1 January 1979 - 14 March 1979) (day 1= beginning of trial, day 73= end of trial). This shows that on or about day 8, water pressure head increased. This was due to rainfall. A first maximum was reached on day 16, then the pressure head decreased. On day 29, the pressure head started increasing again as the field was flooded with river water. Water was continuously applied to the field until day 44, after which water levels generally declined. Slight increases due to rainfall occurred after day 44.

Figures 15 and 16 show flow patterns occurring during the leaching process for both sites. The flow pattern at site 2 (near main drain) indicates water movement toward the main drain as would be expected. Movement of the water was primarily horizontal.

The flow pattern at site 1 (near the operating 4 foot drain) during flooding was ill-defined. One reason for this is believed to be a low flow rate caused by a small hydraulic gradient and an apparent low hydraulic

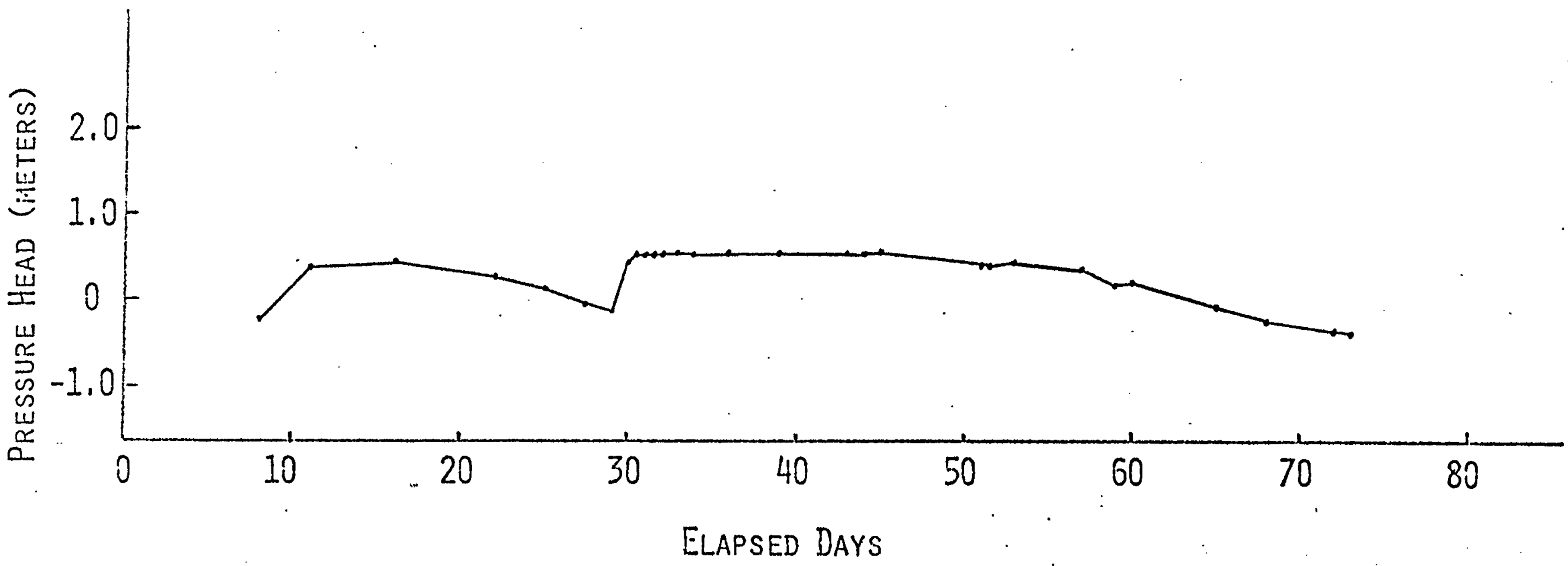



FIGURE 14. PRESSURE HEAD CHANGES WITH TIME, EMPIRE TRACT (DAY 0 = 1 JANUARY 1979), (ONE-FOOT DEPTH).

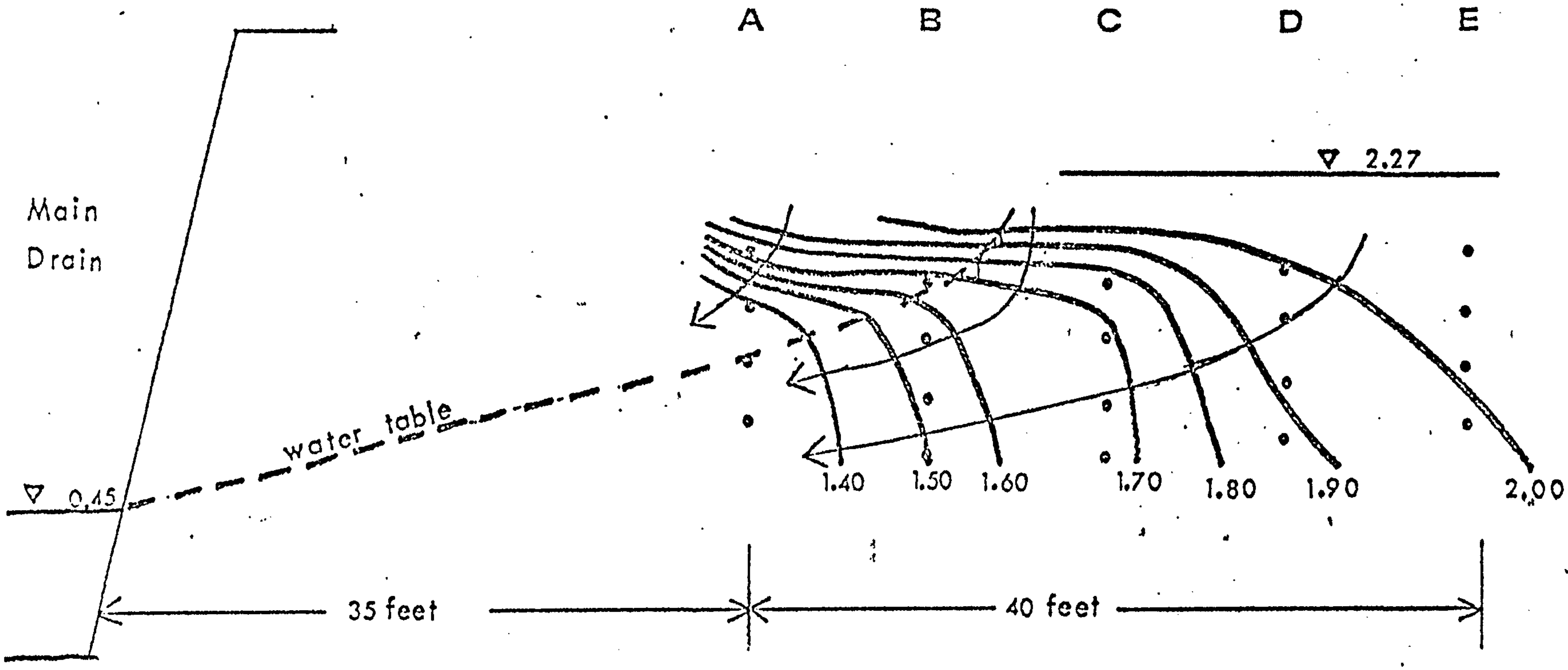



FIGURE 15. GRID SYSTEM AND LINES OF EQUAL HYDRAULIC HEAD, MAIN DRAIN SITE, EMPIRE TRACT, 30 JANUARY 1979 (DAY 30)

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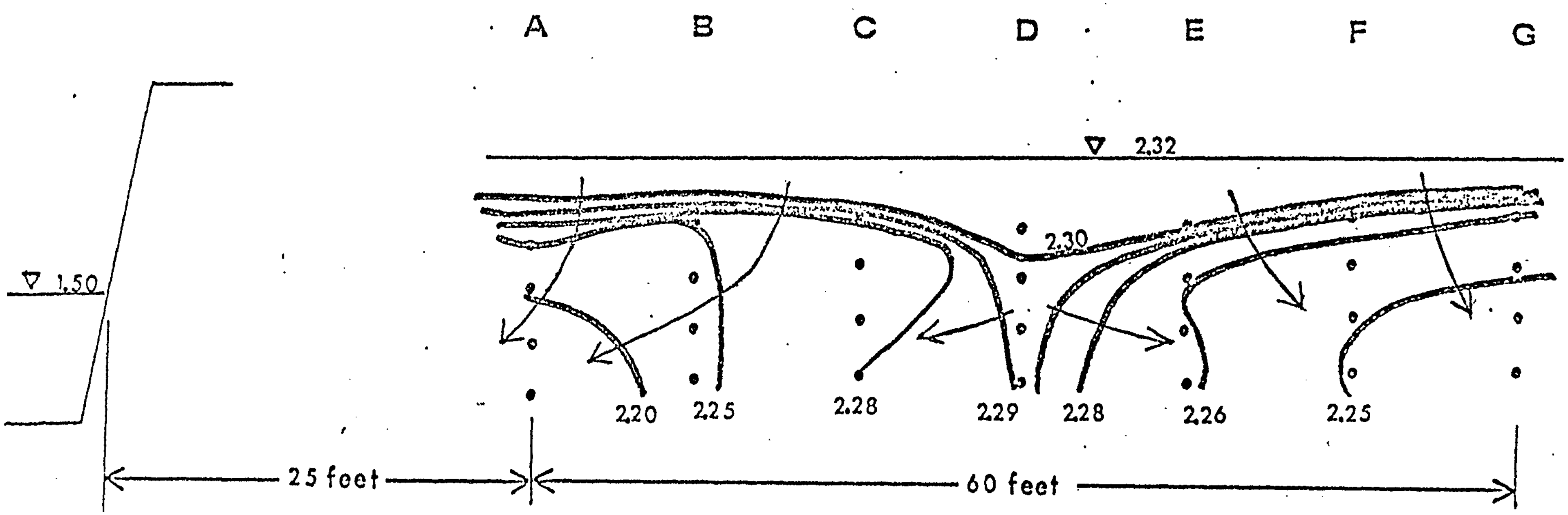


FIGURE 16. GRID SYSTEM AND LINES OF EQUAL HYDRAULIC HEAD, FOUR-FOOT DRAIN SITE, EMPIRE TRACT, 30 JANUARY 1979 (DAY 30)

conductivity of the soil. The small gradient occurred because the drain ditches were nearly full during the flooding period. A second reason is a distortion in the flow pattern at D. This distortion is believed to be due to a field-in spud ditch at that location.

Figures 17, 18, and 19 show changes in EC of the soil water of the saturated soil with time during the leaching process at the one, two, three, and four foot depths for distances from the four-foot drain of 25 feet, 45 feet, 75 feet, respectively. Nearest to the drain, salts were rapidly removed with time at the one foot depth but as the distance from the drain increased, the leaching process was slower. This is to be expected. However, the one foot depth at the 75 foot distance, significant amounts of salt remained at day 73. This indicates that the drain is effective for a distance of 50-60 feet.

The data also shows little change in subsurface water quality at the two, three, and four-foot depths with time regardless of the distance from the drain. This is particularly interesting since considering the magnitude of changes in EC at the one-foot depth, one would expect some substantial change in EC with time at least the two foot depth particularly since the flow pattern indicated a downward component of the flow. However no substantial change occurred. This data may indicate that vertical water movement is very slow and as a result, little of the salts leached from the surface soil was transported down to the two foot depth. The cause of this phenomena is believed to be a very dense layer of buckskin at about 1 1/2-2 feet below the surface, which may have very small vertical hydraulic conductivity. This will be verified this summer.

Water quality of the drain water and leaching water is listed in Table 8.

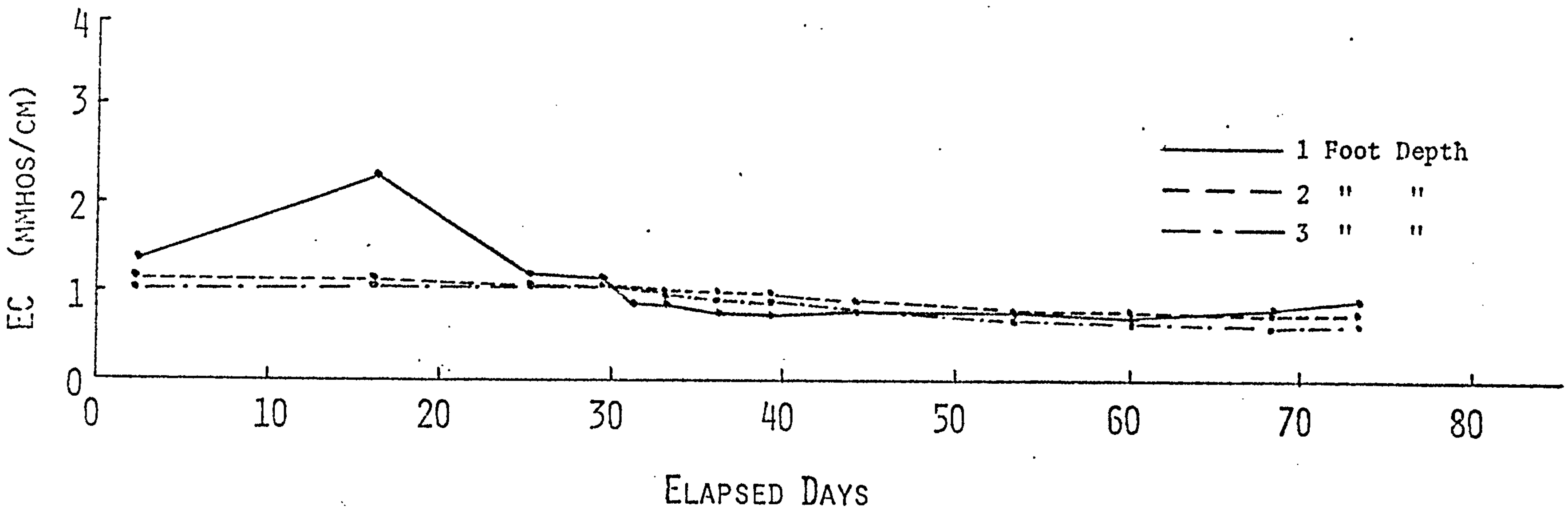


FIGURE 17. CHANGES IN EC WITH TIME DRUING LEACHING AT EMPIRE TRACT. DISTANCE FROM 4-FOOT DRAIN IS 25 FEET.





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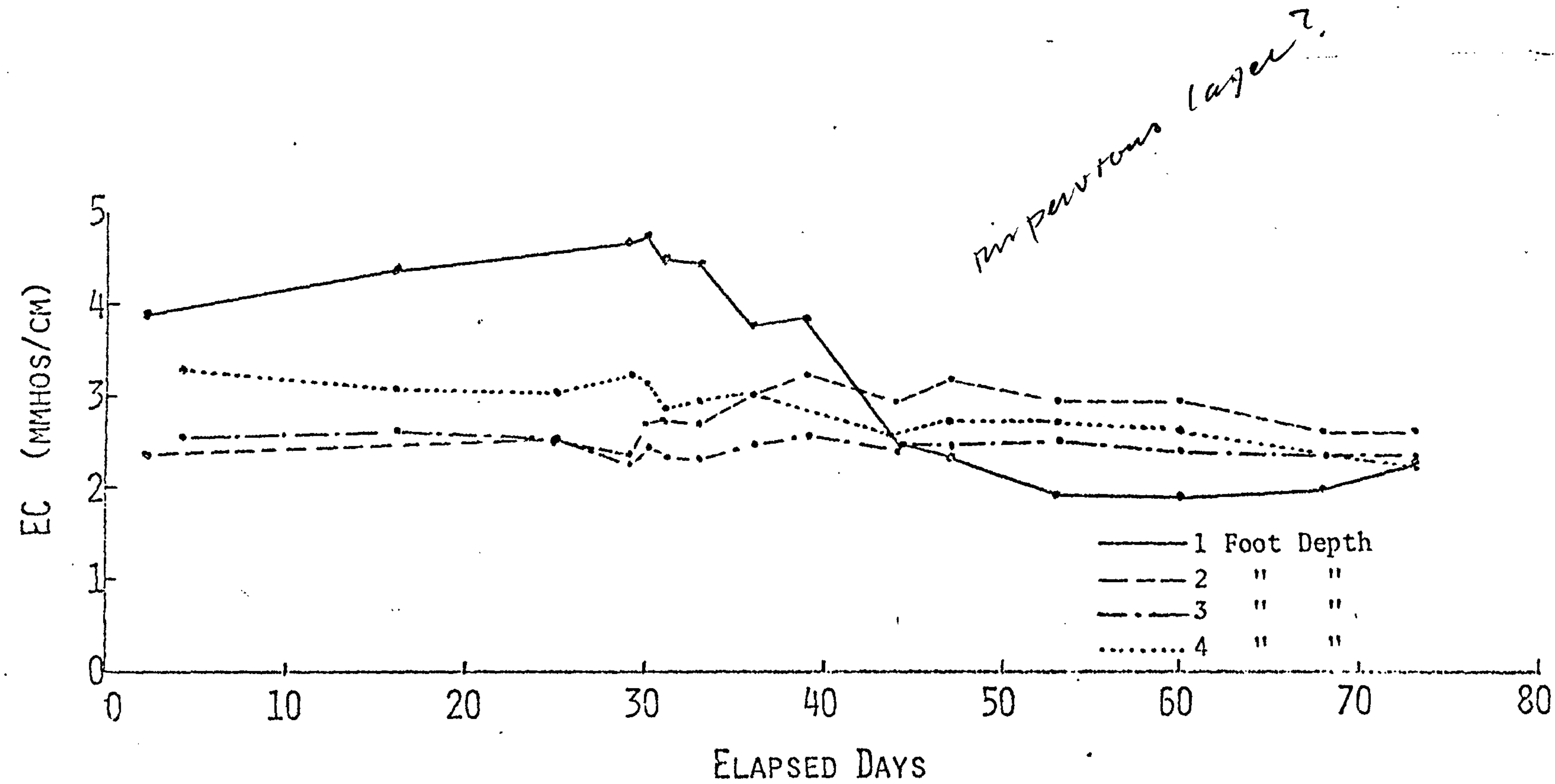


FIGURE 18. CHANGES IN EC WITH TIME DURING LEACHING AT EMPIRE TRACT. DISTANCE FROM 4-FOOT DRAIN IS 45 FEET.

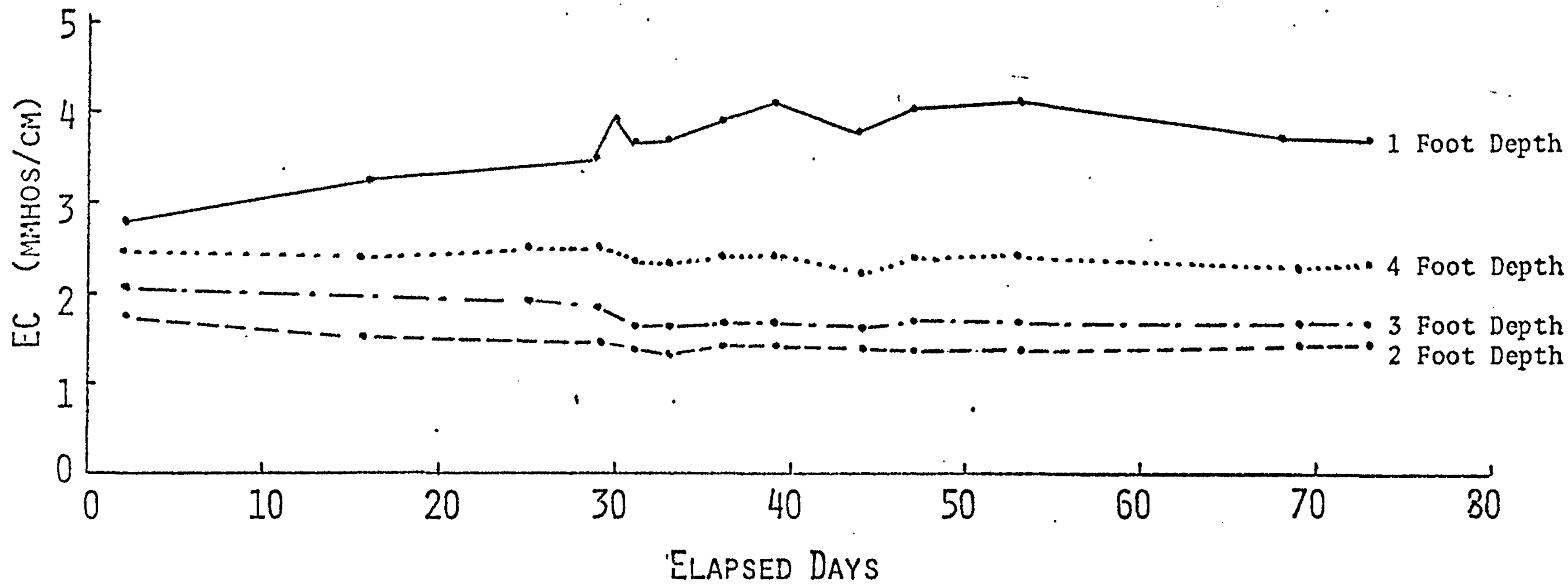


FIGURE 19. CHANGES IN EC WITH TIME DURING LEACHING AT EMPIRE TRACT. DISTANCE FROM 4-FOOT DRAIN IS 75 FEET.





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An analysis of soil salinity data obtained before and after leaching (Table 9) showed a decrease in soil salinity in the top foot but an increase in salinity below the one foot depth. Although, the subsurface water quality samples showed little change in quality with time during the process, it may be that during the drainage of the field, salts leached from the first foot were moved downward. If this be the case, then based upon soil salinity changes during the irrigation season, leaching of these salts may occur during the irrigation process.

## LABORATORY EXPERIMENTS ON PEAT SOILS

### Salt Movement.

When a solution of one quality flows through a soil initially containing a solution of a different quality, the initial solution is gradually displaced by the inflow. This process is called miscible displacement since if aqueous solutions (for a soil system) are involved, some mixing of the two solutions occurs. The rate at which this displacement process proceeds depends on factors such as pore size distribution of the soil, flow velocity, diffusion, chemical constituents of the solutions, ion exchange, precipitation, etc.

The method used to determine miscible displacement characteristics of a soil is to flow solutions through samples of soil and measure the volume of effluent from the sample and concentration of ions in it as function of time. A breakthrough curve can then be developed which provides information on salt removal characteristics of the soil.

Table 8. Water Quality Data of Leaching Trial, Empire Tract. (mmhos/cm)

| Date | Main Drain* | Four-Foot Drain* | "V" Ditch | Leaching Water |
|---|---|---|---|---|
| Jan 30, 1979 | 1.11 | 0.90 | - | 0.45 |
| Feb 1, 1979 | 1.04 | 0.87 | - | 0.46 |
| Feb 5, 1979 | 0.93 | 0.86 | 2.56 | 0.50 |
| Feb 8, 1979 | 0.90 | 0.83 | - | 0.50 |
| Feb 17, 1979 | 0.96 | 0.90 | - | 0.45 |
| Feb 23, 1979 | 0.58 | 0.94 | 2.36 | 0.23 |
| Mar 2, 1979 | 1.61 | 1.26 | - | - |
| Mar 10, 1979 | 1.91 | 2.10 | - | - |

*During the beginning of the trial, the open-ditch drains contained runoff from the rainfall. This resulted in low EC values.

Table 9. Soil Salinity Changes During Leaching, Empire Tract. (four-foot drain)*

| Depth (feet) | ECe (mmhos/cm) Dec. 20, 1978 | March 16, 1979 |
|---|---|---|
| 1 | 2.97 | 1.62 |
| 2 | 1.75 | 2.28 |
| 3 | 1.33 | 1.91 |
| 4 | 3.47 | 3.20 |

*This pattern was consistent at most sampling locations.

Miscible displacement experiments were conducted on peat soils to determine the characteristics of peat soils in regard to salt movement in the soil. It was hoped that information from these experiments could be used to help describe the leaching process as it occurred in the field.

Undisturbed samples of soil from the profile at the MacDonald Island site were used. These samples were obtained from a surface layer, a sub-surface buckskin layer and a layer of mixed mineral and peat. Breakthrough curves for the surface soil and the "buckskin" are shown in Figures 20 and 21, respectively, for the desalinization process.

Figure 20 shows that one pore volume of through-flow removed about 70 percent of the sodium and chloride in the surface layer. Na and Cl were removed from the soil sample at the same rate for concentrations above 9-10 meq/l, but the rate of removal of Na was slower than that of Cl for smaller concentrations. The difference is believed to be due to sodium adsorption by the soil.

Figure 21 shows that one pore volume of flow-through removed about 66 percent of the $Na^+$ and $Cl^-$ in buckskin. This behavior is similar to that of the surface layer although adsorption of $Na^+$ by the soil are believed to be insignificant. Reasons for this could be that buckskin has little tendency to absorb cations or because of the lower bulk density of the buckskin compared to that of surface layer resulted in fewer exchange sites in the buckskin compared to that of the surface soil.

If the assumption is made that the processes which occurred in the laboratory also occurs in the field, then an estimate of the volume of water required to leach one foot of soil can be made. For the surface layer, approximately one foot of water will remove about 75-85 percent of the salts per foot of depth. For the buckskin, one foot of water will remove about

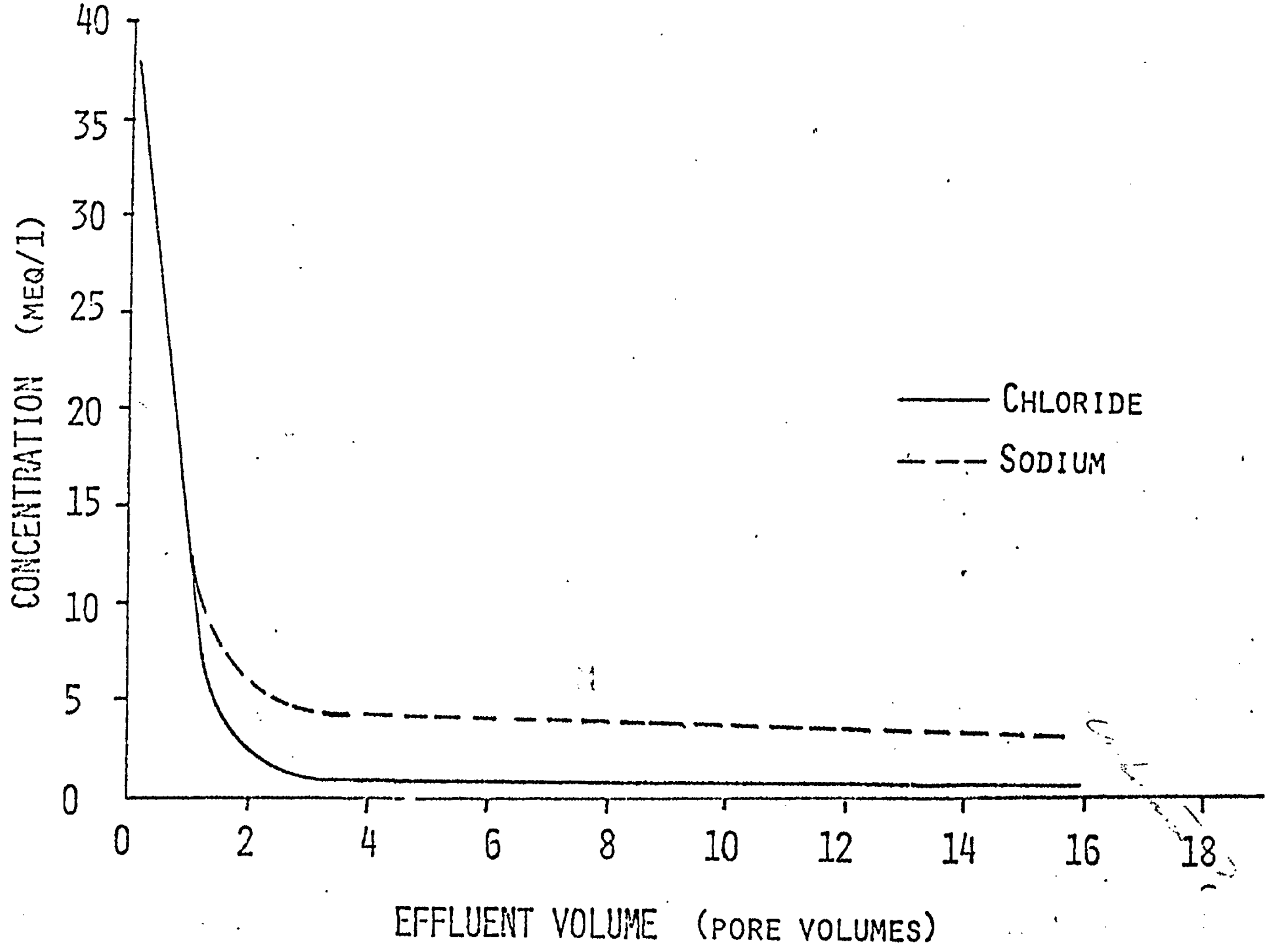


FIGURE 20. BREAKTHROUGH CURVE FROM SURFACE SOIL- MACDONALD ISLAND

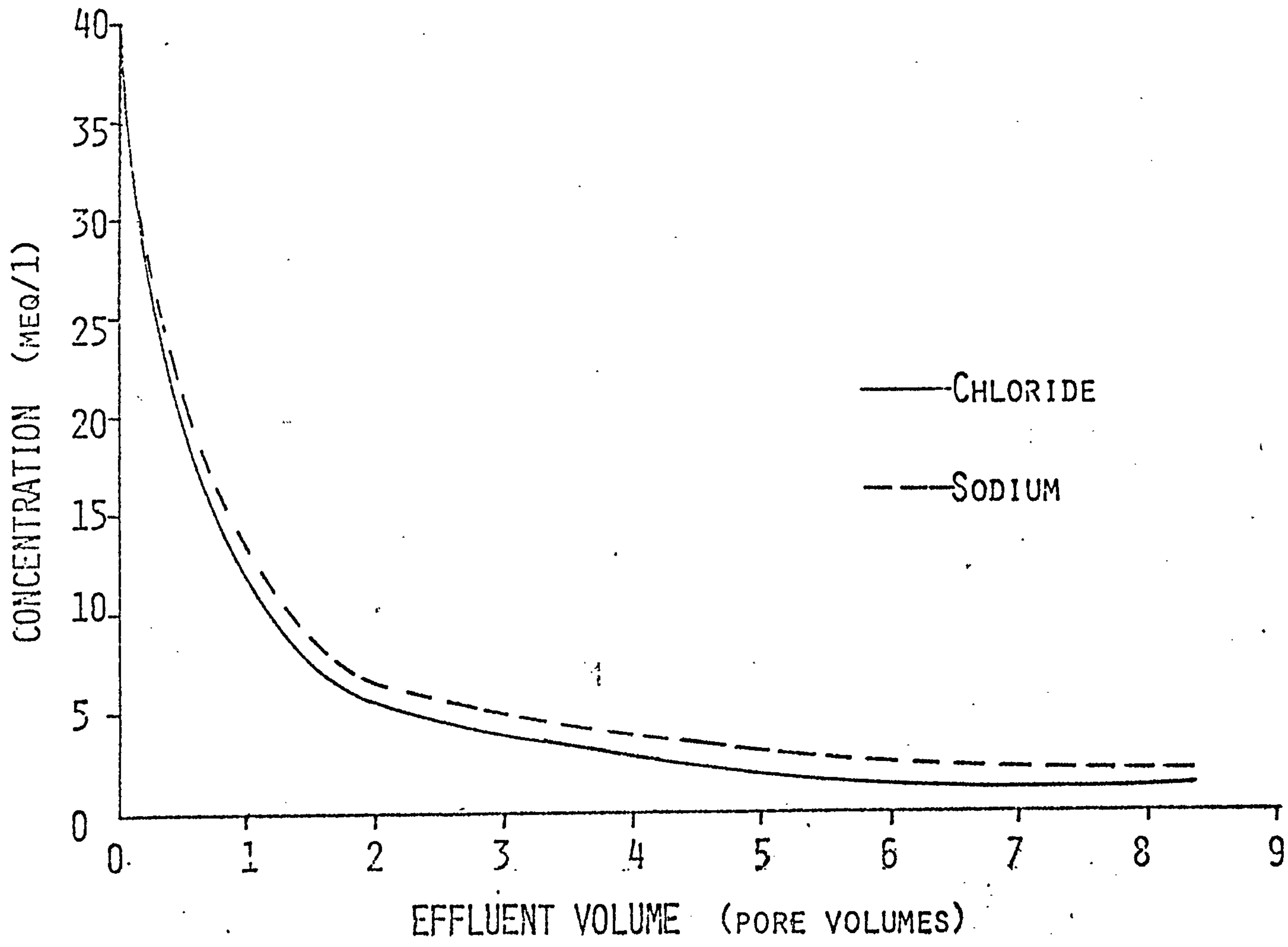


FIGURE 21. BREAKTHROUGH CURVE FOR BUCKSKIN- MACDONALD ISLAND.



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70 percent of the salt per foot of soil. This applies only for saturated conditions, and where no cracks occur in the soil. Under unsaturated conditions it appears that 0.7 feet of water will remove about 80 percent of the salts per foot of depth for the surface layer.

Moisture Retention Curves.

Figures 22 and 23 show the moisture retention characteristics of the surface soil and the buckskin at the McDonalds site. At saturation the water content for the surface and buckskin was about 0.74 and 0.89, respectively on a volume basis. Rapid desaturation of the surface soil occurred within the first 50 centimeters of soil suction. Upon resaturation, the water content of the surface layer was about 0.69. This difference is attributed to entrapped air and slight shrinkage of the soil sample.

However, during the desaturation cycle of the buckskin, significant shrinkage of the soil occurred. Thus, if the water content was calculated using the actual bulk volume, little change in water content occurred. For every unit volume of water removed from the sample, there was a unit change in bulk volume due to shrinkage.

The implications of this behavior are two-fold: First, moisture-retention curves of buckskin cannot be used to determine changes in soil moisture by using soil suction data as is commonly done with mineral soils; second, when buckskin is desaturated under field conditions such as occurs when the water table drops, what changes in bulk volume occur and how are these changes manifested througout the soil system. Answers to these questions are unknown at this time.

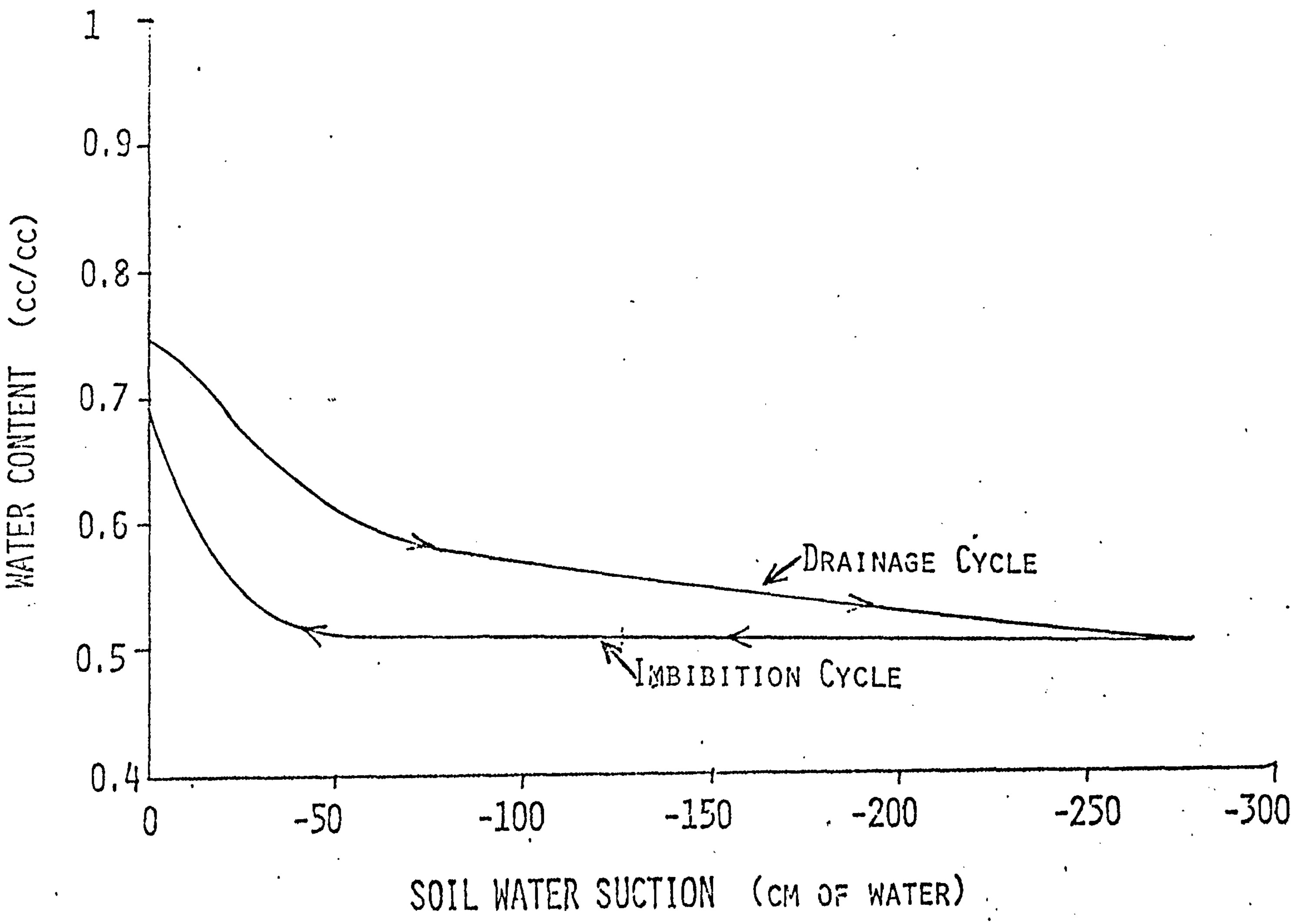


FIGURE 22. MOISTURE-RETENTION CURVE FOR SURFACE SOIL- MACDONALD ISLAND.

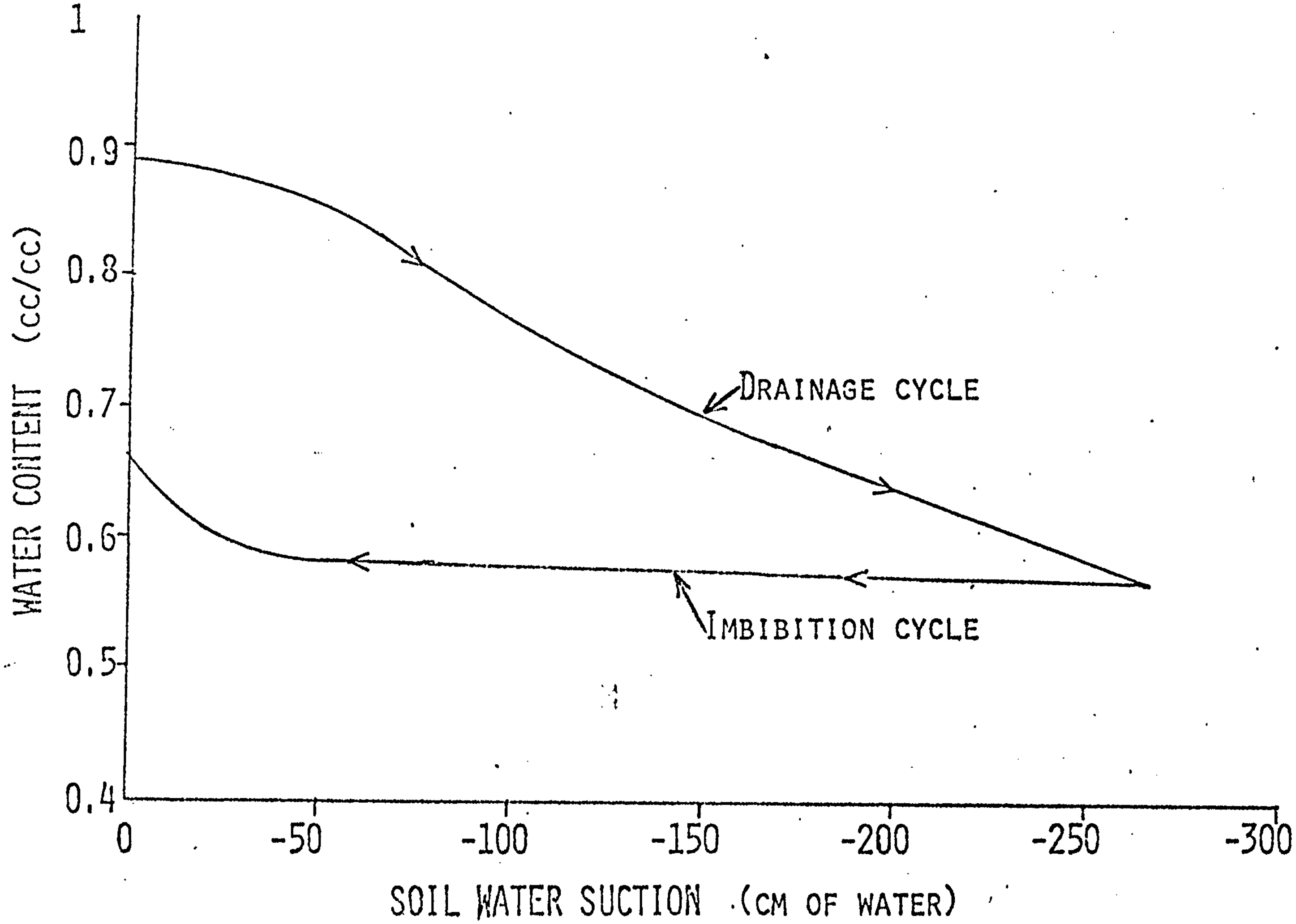


FIGURE 23. MOISTURE-RETENTION CURVE FOR BUCKSKIN- MACDONALD ISLAND





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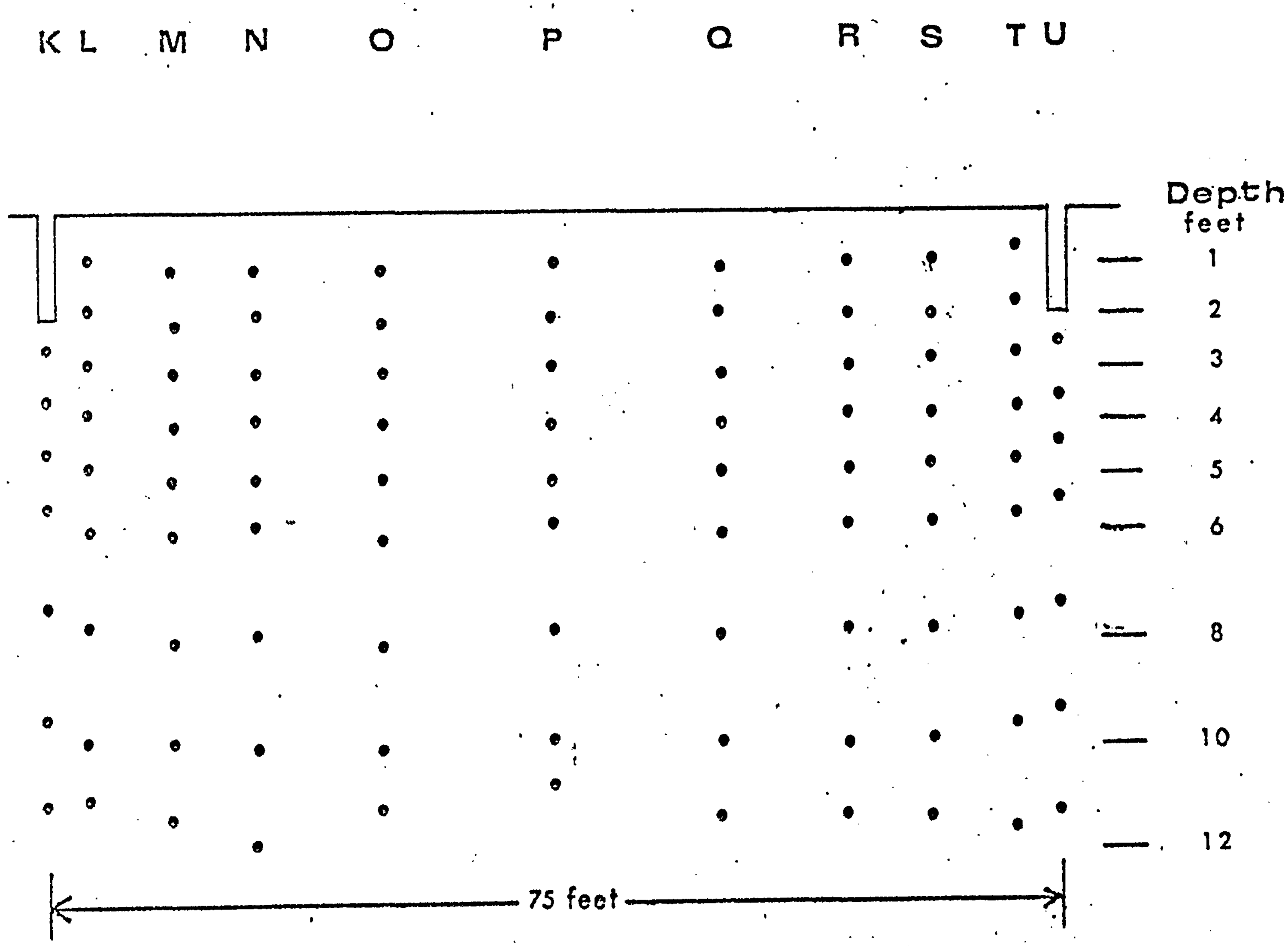


FIGURE 26. GRID SYSTEM OF PIEZOMETERS- VENICE ISLAND

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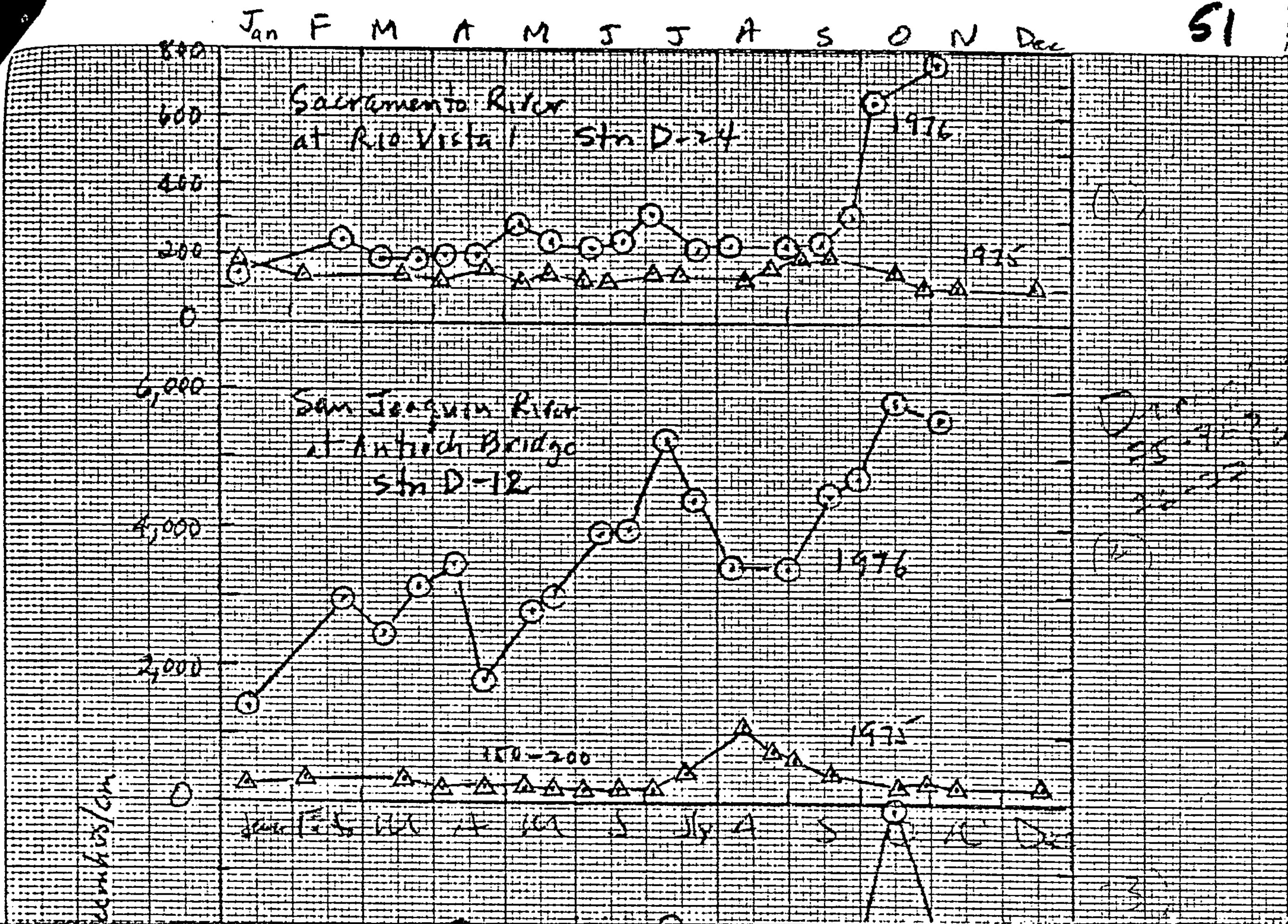



# Subirrigation in the Delta

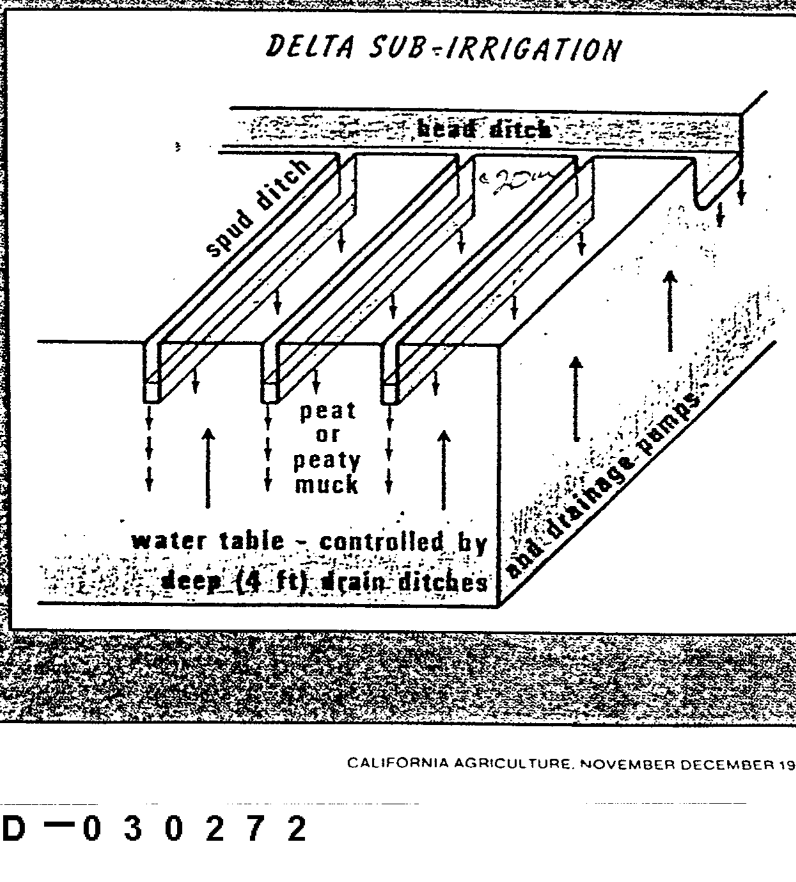
The peatlands of the Sacramento-San Joaquin Delta are irrigated almost entirely by subsurface methods. Gravity surface irrigation is not suited to these organic soils because of high infiltration rates and variable subsidence which makes surface distribution difficult. Sprinkler irrigation is an alternative, but is not widely used because of the high capital outlay and high energy costs.

In a typical Delta subirrigation system, water from the river channel is siphoned over the levee and into a system of unlined head ditches and small lateral ditches ("spud ditches") cut into the peat soil. Spud ditches are 6 inches wide, from 10 to 24 inches deep and are commonly spaced from 40 to 80 feet apart. (See illustration.)

Several times during each irrigation season, the spud ditches are filled. This quickly raises the water table in the porous peat soil from a depth of 3 or 4 feet to within 6 to 10 inches of the surface. Water stored in the root zone, which in peat may be as much as 6 inches per foot of soil, is then depleted by the crop and by evaporation from the soil surface. As a result, the water table gradually drops until irrigation is necessary again.

Drainage is provided by larger and deeper ditches cut from 300 to 1,000 feet apart. These are connected to a main drain, 7 to 10 feet deep, through which water flows to a pump and is returned to the river.

*Ray Coppock*



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## CONCLUSIONS

Grids of piezometers were installed between spud ditches in corn fields on Rindge Tract, Venice Island and Bouldin Island. Periodic readings at these piezometers during and following irrigation permitted the study of subsurface water flow and to assess the possible contribution to root zone moisture by upward moving ground water.

Grids of piezometers were installed at two locations in a field on Empire Tract which was leached (flooded) during the winter. Readings were taken under non-flooded rainy conditions and under flooded conditions in order to study water flow during leaching.

At all piezometer sites, grids of suction probes were installed to periodically sample subsurface water quality. During the summer, it was hoped that the better quality (lower salinity) irrigation water would act as a tracer for water movement during irrigation. For reasons not well understood at this point, this did not work. During the winter, these periodic samplings of subsurface water successfully reflected the leaching process.

At all three sites, despite considerable profile differences, water moved rapidly horizontally into the soil with no important displacement of the ground water upward. Thus, the water replenishing the root zone was the irrigation water. The rapid horizontal movement was believed to be due to a network of subsurface soil cracks.

The Bouldin plot appears to have a source of unknown magnitude of subsurface water between the six to eight foot depths. This water contains sulfate whereas most other shallow ground water contains no sulfate. This water cannot be coming from the river through a "clean" aquifer since sulfate is far too high. The source of this water is unknown. The question arises as to how extensive are such areas in the Delta. Any conclusion drawn with respect to the relation of irrigation water quality (defined as diverted surface waters) to soil salinity, and hense crop response, may be affected by such conditions.

It is widely known that cracks occur in the peat subsoil. It is not clearly understood how extensive they are or to what extent they form a continuous network of channels. Observations of piezometers during the first phase of an irrigation and the rate of appearence of water in holes dug into the shallow water table during an irrigation suggest that there may be extensive cracking in the subsoil through which water rapidly moves horizontally from the spud ditches.

If further study should show these cracks to be a continous network through which water can move readily in a horizontal direction from spud ditch to soil during irrigation and from soil to drainage ditch during leaching, then this will have important implications with respect to both the irrigation process and the leaching process if such crack networks are widespread in the Delta soils. Specifically, both irrigation and leaching can be more efficient than they would otherwise be and new management methods can perhaps be developed to improve the present practices.

Salinity of subsurface water from 60 cm to 150 cm, showed little change with time during an irrigation, even near a spud ditch (except in one case). This is surprising in view of the rapid water movement. The reason for this behavior is unknown at this time.

Analyses of saturation extracts of soil samples when compared to subsurface water analyses (sampled in-situ from in-place ceramic cups) show anomalous results in two important aspects. First, soil analysis indicates considerable more total soil salinity than would be estimated from subsurface water samples. Second, although sulfate diminishes with depth in the water samples and in essentially nil at 120 cm and deeper, it is much higher in the soil samples and increases with depth. It is possible that these anomolies may be caused by an artifact in the standard preparation of soil for analysis. This is to be investigated in the second year of this study.

During the leaching trials, considerable salt was removed from the top 30 cm but did not appear to move into the zone below. The question arises: if the salts did not move into the zone below 30 cm, where did it go? If it moved horizontally 20 to 40 meters to a drain ditch but did not move deeper than 30 cm, this would indicate the existence of a barrier at about 30 cm that is highly impermeable to vertical movement. The 30 cm-60 cm horizon is not a clay but rather a layer of compact "buckskin" in row peat. It is anticipated that this field will be studied in considerable detail in summer '79' and perhaps winter '79-80'.

Soil salinity data obtained during the leaching trial showed a decrease in salt in the first foot but an increase below the one foot depth. Thus, it appears that salts which accumulated in the top layer during the irrigation season are leached down to depths below one foot and, based upon soil salinity changes over the irrigation season, leaching of these salts occurs during irrigation.

## REFERENCES


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Boast, C.W., and Don Kirkham. Auger Hole Seepage Theory. Soil Sci Soc Proc, Vol. 35, No. 3, May-June 1971, pg 365-373.

plane skimmed below us, dusting fertilizer. Two brown plumes of peat dust rose in the air, marking the movement of distant tractors. At our feet, rusty pipes siphoned river water over the levee to the fields. Nothing else linked this scene of mechanized farming with the water labyrinth behind us.

Few but farmers and pleasure boaters know this delta, and they are curtained from each other by 1,100 miles of levees that rim 55 islands reclaimed from marshland. This is the water crossroads of California, where the state's longest rivers—the Sacramento and San Joaquin—meet to flow westward to San Francisco Bay and the Golden Gate. Like coastal deltas it is triangular, but this one lies inland, behind mountains. It extends no more than 70 miles on any side (map, right).

### Green Heart of the Golden State

The California Delta is an isolated remnant of other times, woven in its own watery web near the center of the nation's most populous state. Only nine of its islands have towns, none larger than about 1,000 residents. No major highways cross it, and Californians in a hurry avoid its ponderous drawbridges and tiny cable ferries. Some farm islands, owned by affluent city dwellers or corporations, are inhabited only by foremen and laborers living in barracks. Others, like Bethel, are rimmed with marinas serving pleasure boaters from the cities. Some, like Venice, are owned by hunting clubs. Their cornfields lure ducks and geese migrating along the Pacific flyway.

The people of the delta recall the passage of years not by civic triumphs but by natural disasters. The levees give them a tenuous hold on the land. It can be lost when floodwaters from winter rains and melting Sierra snows surge through the delta on their way to the Pacific, or wind-whipped tides drive up from the sea. Even a tiny burrowing animal can cause a catastrophe by weakening a levee against the gnawing current.

We stood atop a levee one day with Ed Wilson, a marina owner who serves as a trustee of the Andrus Island levee district. From beneath his battered cap brim, Ed looked warily out on the broad waters.

"Everything depends on these levees, and when they go it's chaos," he said. "We had a break here in 1972, in the middle of the night. That water was like a torrent, rushing into

## The soil's so rich that "anything grows"

IN THE 1850's it was just a swamp to be bypassed by gold-rush prospectors. When the gold fever died, farmers-turned-forty-niners turned farmers again, diked swampland by shovel and wheelbarrow, and planted wheat. They reaped a phenomenal 50 bushels to the acre (today Kansas averages about 35), and the great California land rush was on.

Battalions of Chinese, paid as little as 13 cents for each cubic yard of dirt moved, built more levees. Later, steam-powered clamshell dredges did the work for five cents a yard. By 1930 more than 700,000 acres had been reclaimed. Delta soil—rich peat in the south, rich loam in the north washed down from mountain gold workings—ranks among the world's best. The problem is, some of it is vanishing.

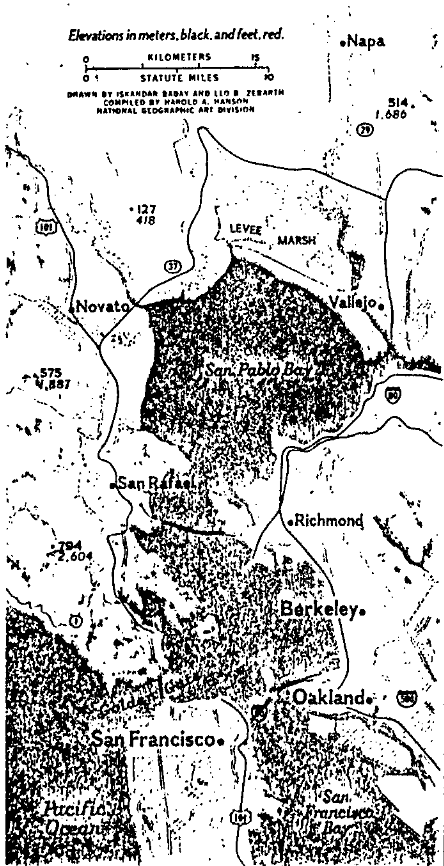
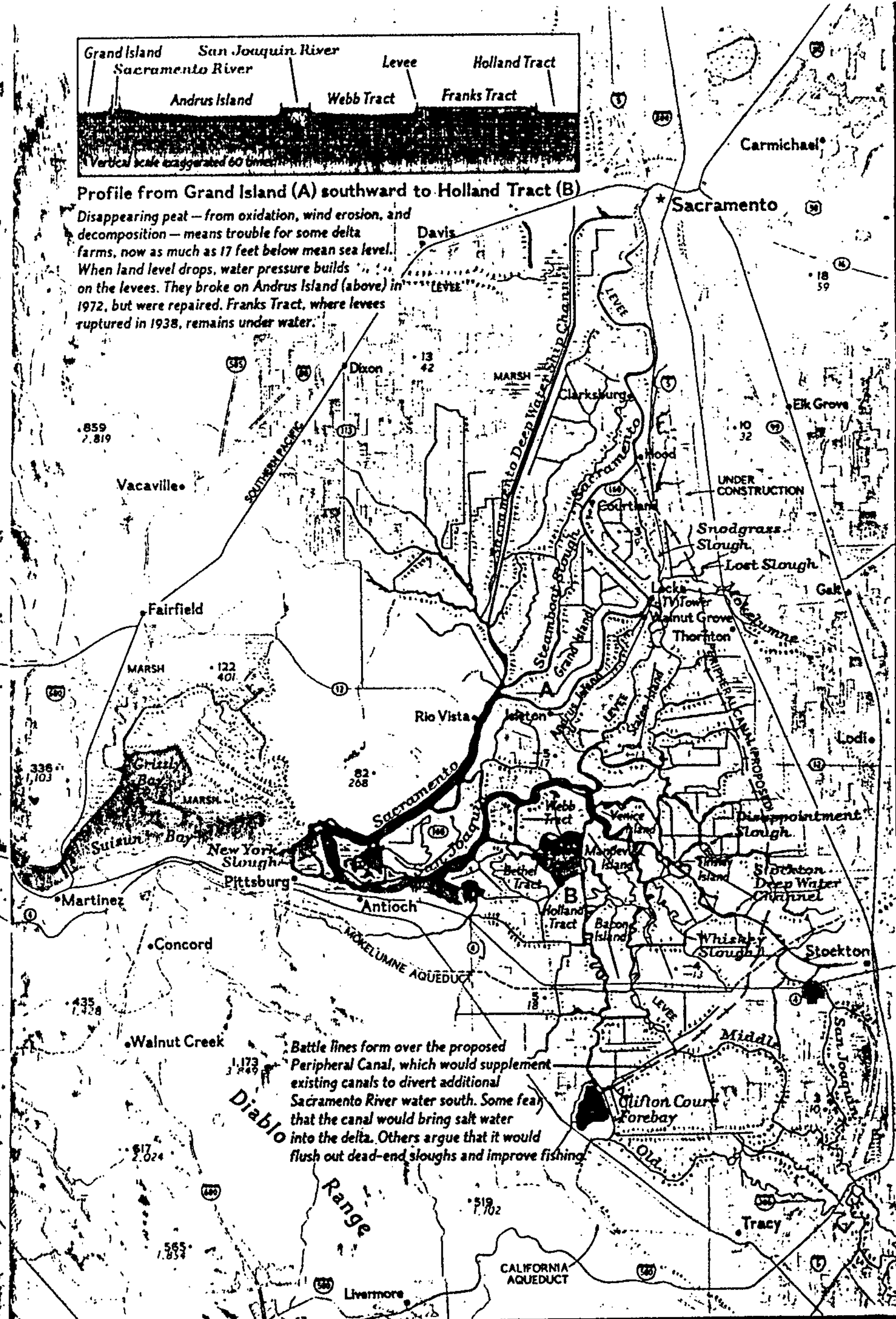

Table 4. Properties of soils at Rindge Tract site.

| Depth (inches) | Number of Samples (n) | Mean | Coefficient of Variation (CV) |
|---|---|---|---|
| (a) Bulk density ($gm/cm^3$) | | | |
| 18 | 4 | 0.33 | 3.8 |
| 24 | 4 | 0.19 | 6.8 |
| 30 | 6 | 0.21 | 12.0 |
| 36 | 6 | 0.32 | 17.5 |
| 48 (mineral) | 3 | 1.70 | 0.7 |
| (b) Percent of organic matter content | | | |
| 18 | 4 | 48.2 | 5.6 |
| 24 | 4 | 71.1 | 5.7 |
| 30 | 6 | 55.0 | 11.6 |
| 36 | 6 | 26.4 | 43.3 |
| 48 (mineral) | 3 | 1.3 | 4.7 |
| (c) Horizontal hydraulic conductivity (cm/sec) | | | |
| 18 | 9 | 0.0034 | 86.0 |
| 24 | 10 | 0.0017 | 68.0 |
| 30 | 4 | 0.00042 | 115.0 |
| 36 | 6 | 0.00018 | 70.0 |
| 48 (mineral) | 3 | 0.000069 | 14.6 |
| (d) Vertical hydraulic conductivity (cm/sec) | | | |
| 18 | 2 | 0.0219 | 7.4 |
| 24 | 11 | 0.0059 | 67.0 |
| 30 | 8 | 0.0122 | 57.0 |
| 36 | 7 | 0.0044 | 83.0 |
| 48 (mineral) | 2 | 0.00061 | 3.4 |



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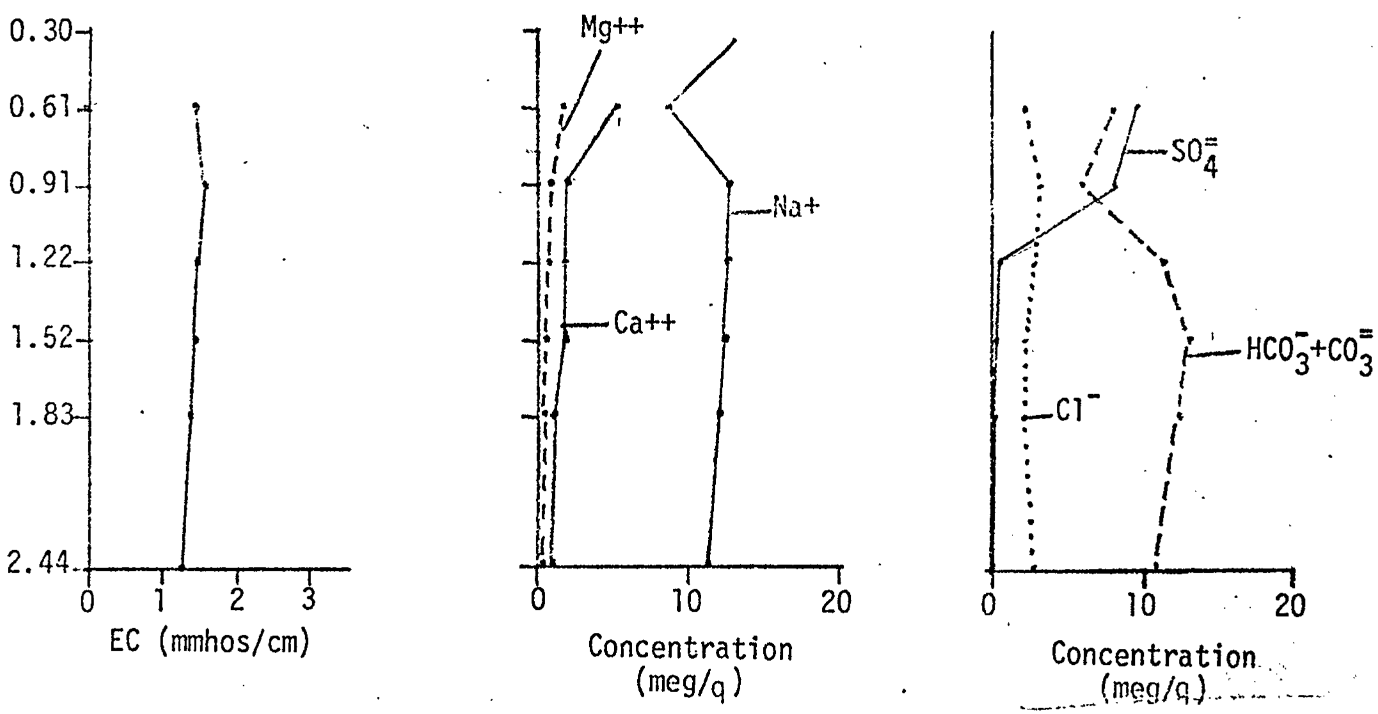


Figure 6. Subsurface water quality, Bouldin Island.

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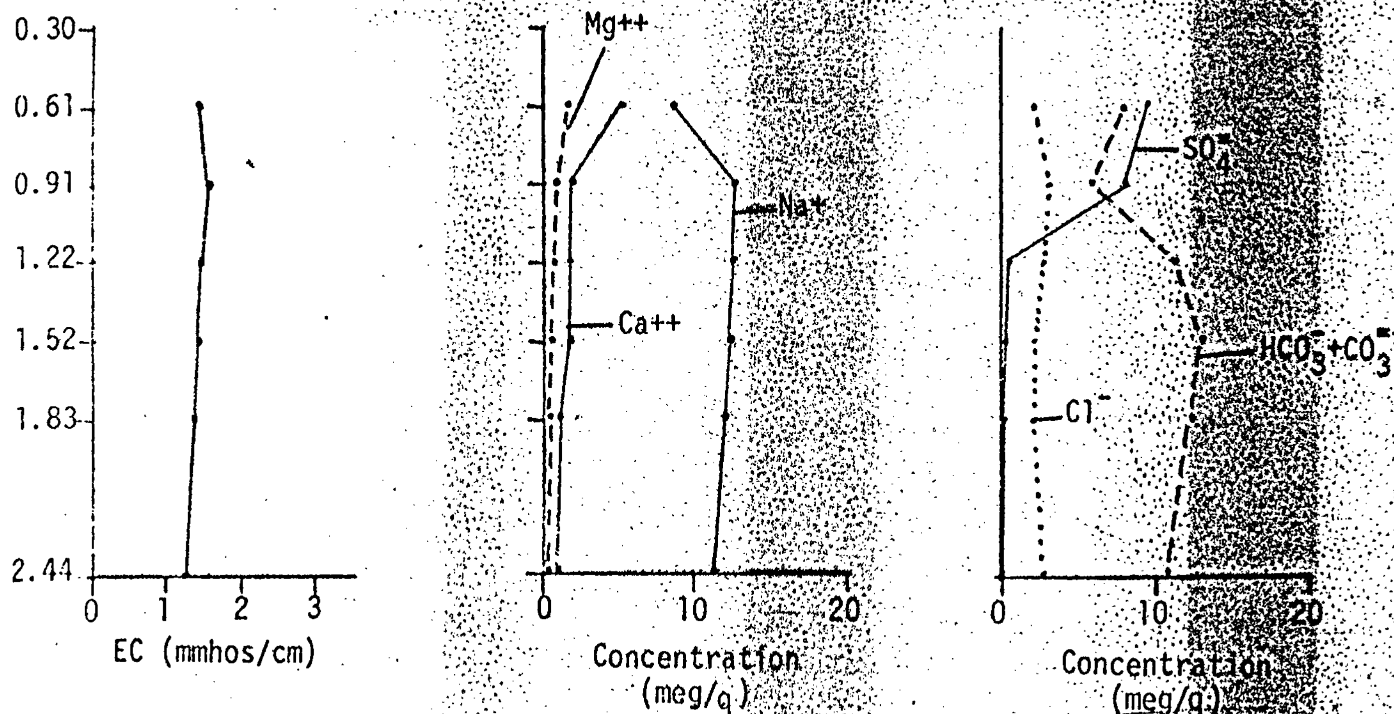


Figure 6. Subsurface water quality, Bouldin Island.

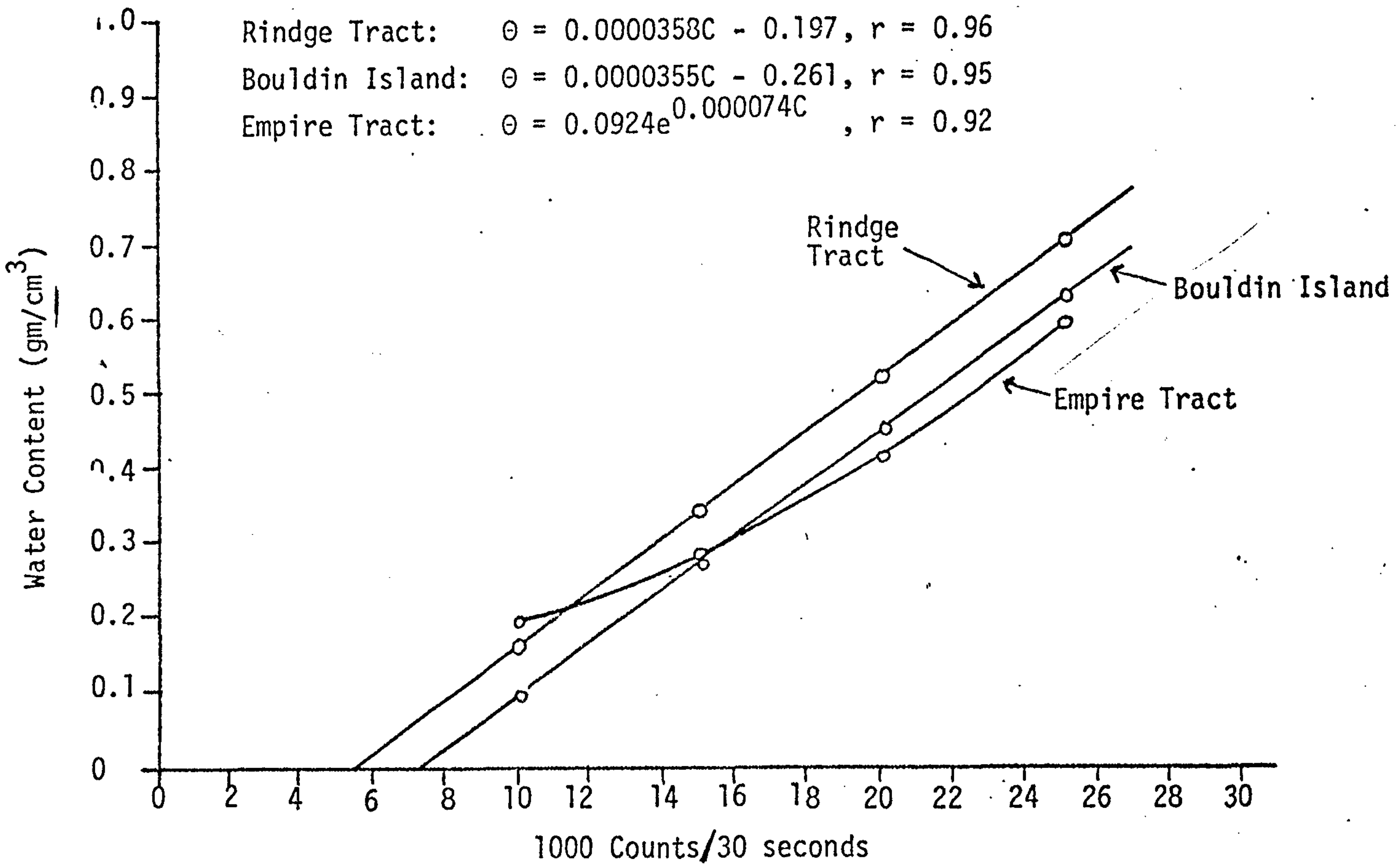


Figure 7. Neutron probe calibration curves.

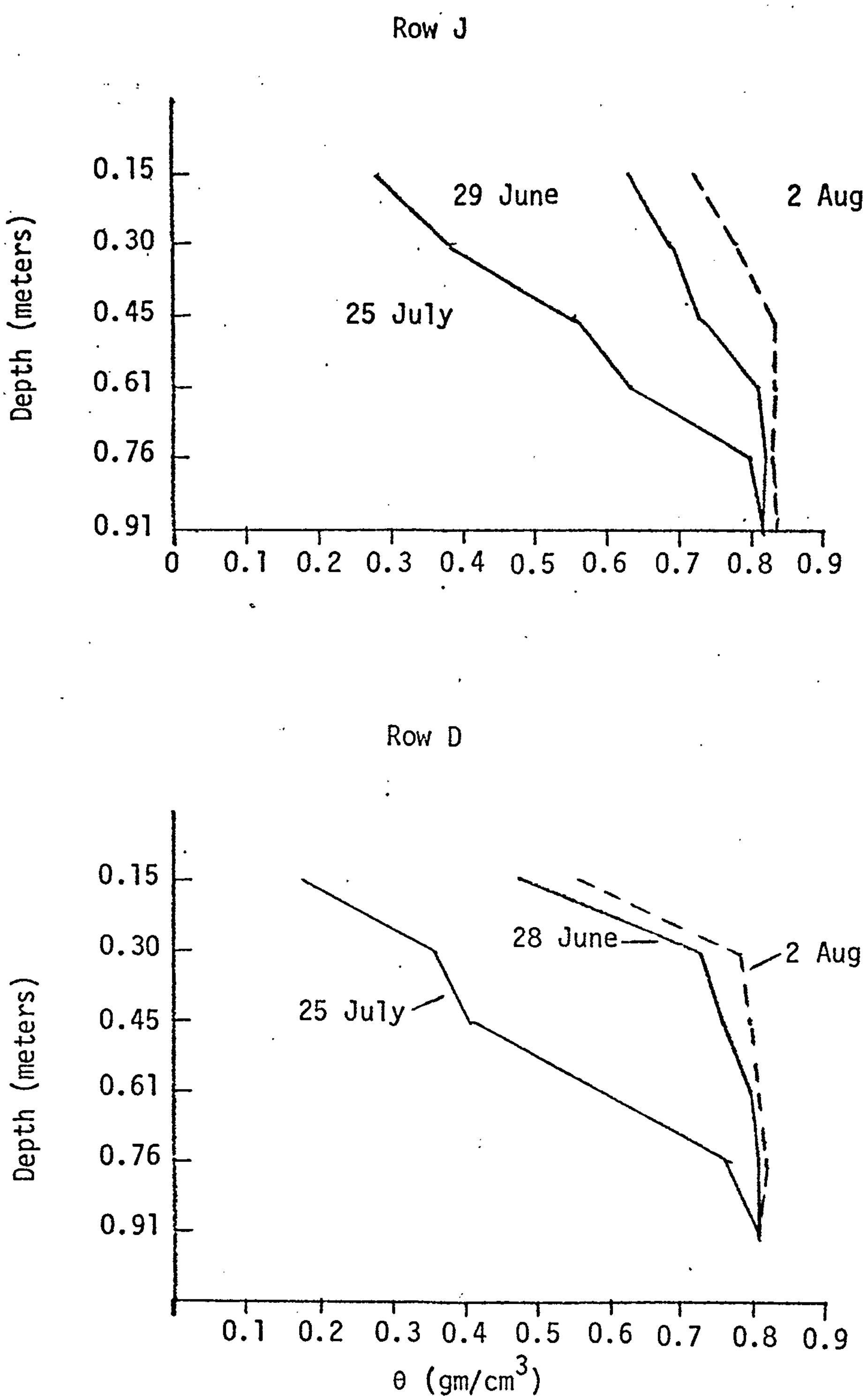


Figure 8. Water content change between irrigations, Rindge Tract.

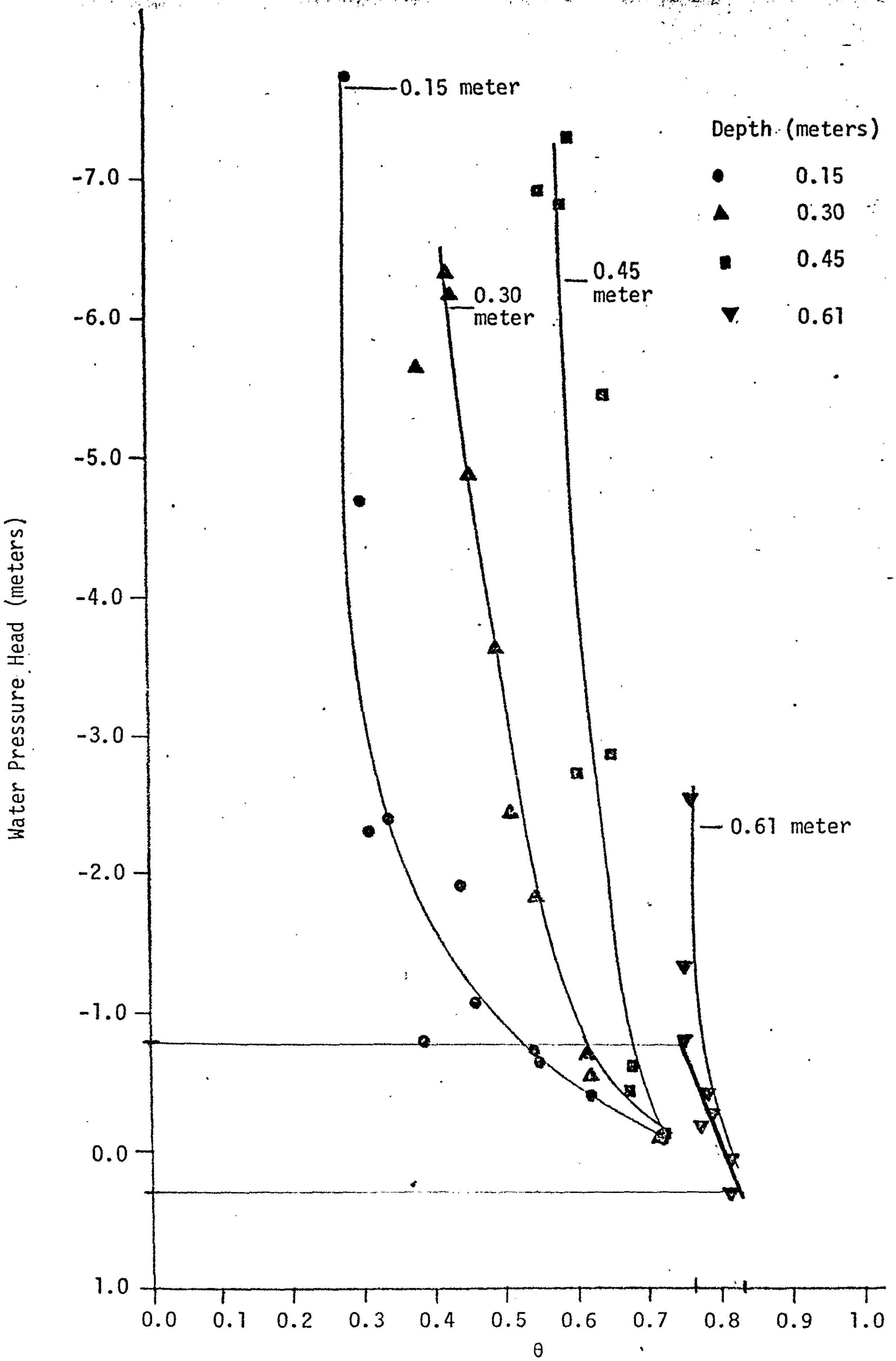


Figure 9. Moisture retention curves, Rindge Tract.

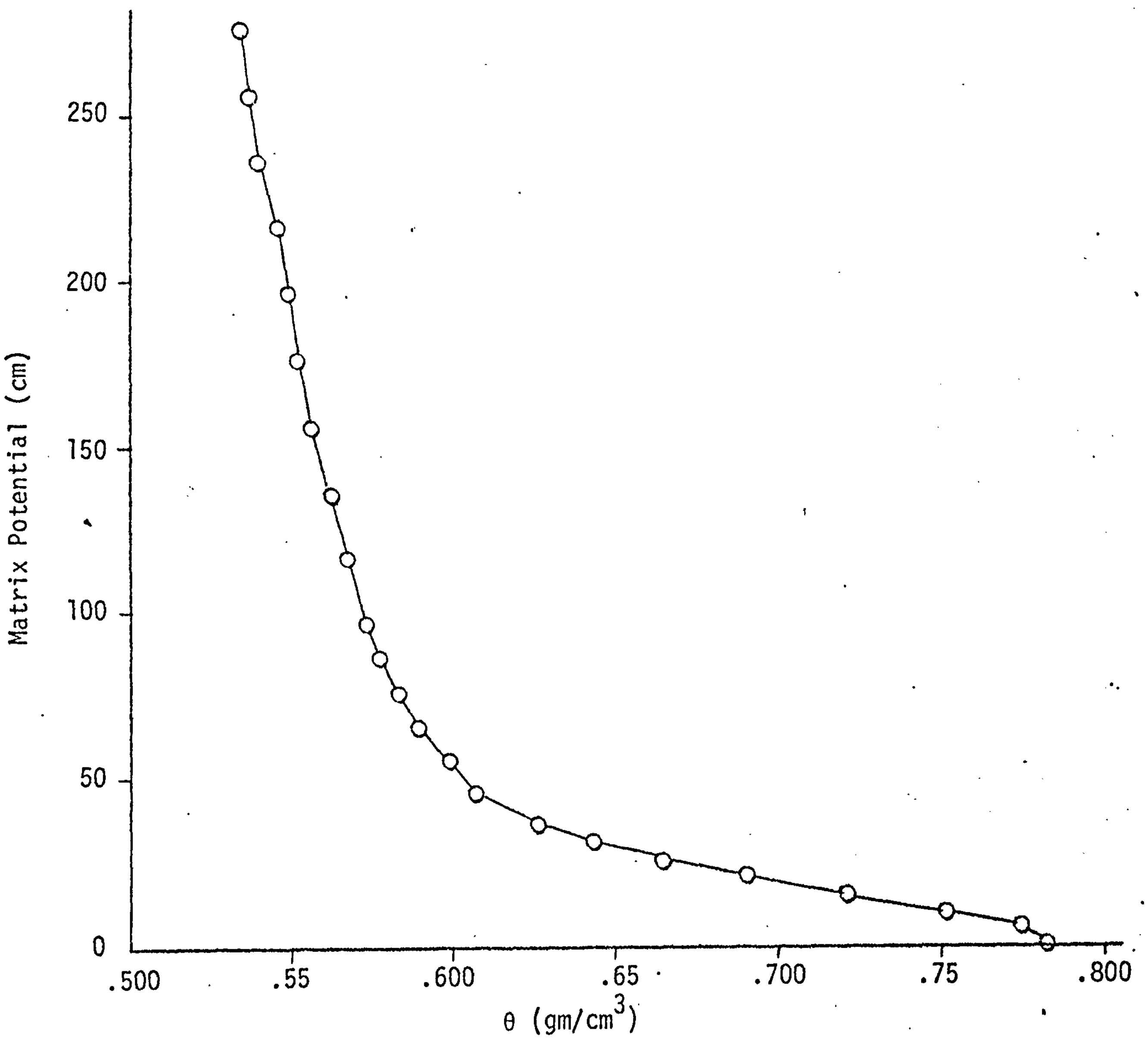


Figure 10. Moisture retention curve of soil at 0.15 - 0.30 meter depth interval, Empire Tract.

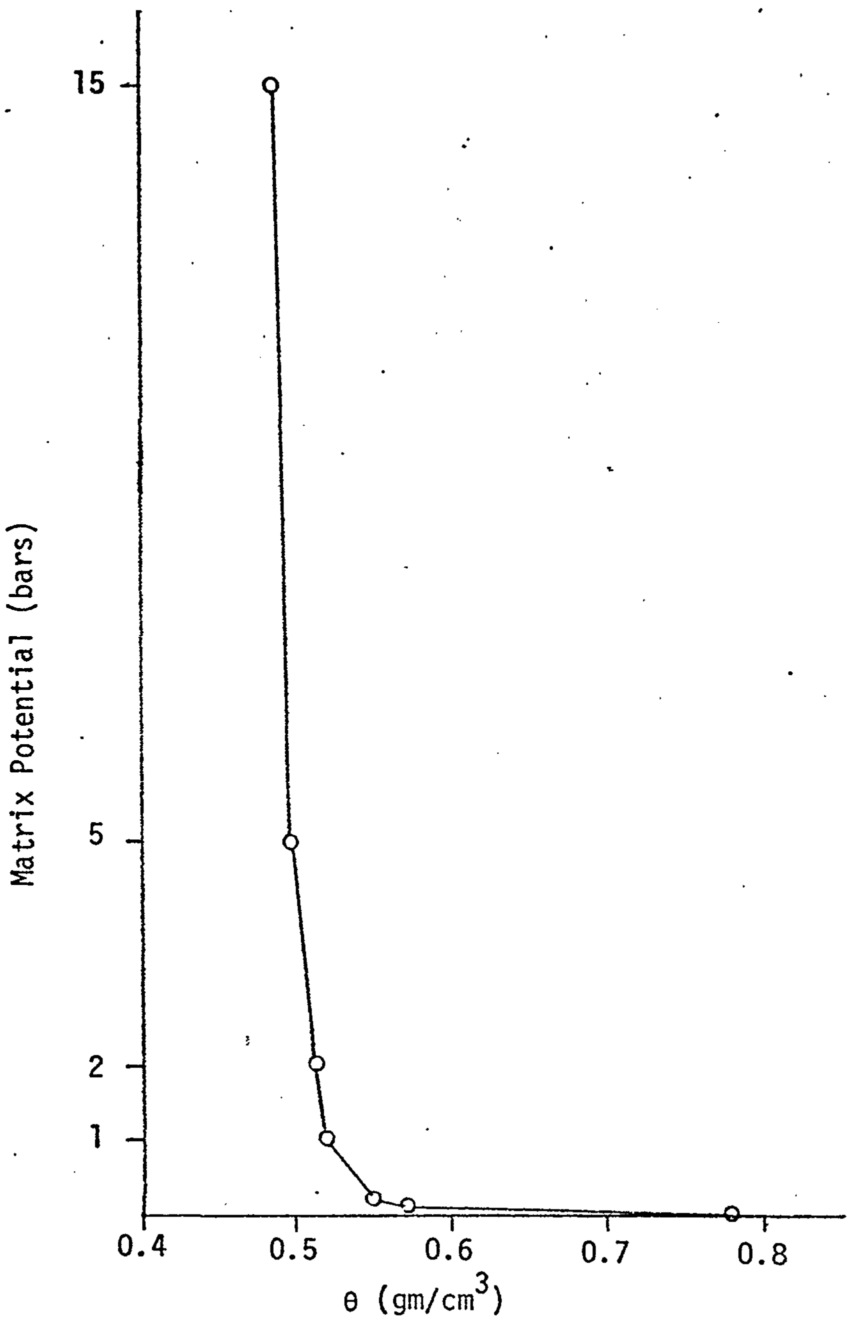


Figure 11. Moisture retention curve of soil at 0.15 - 0.30 meter depth interval, Empire Tract.

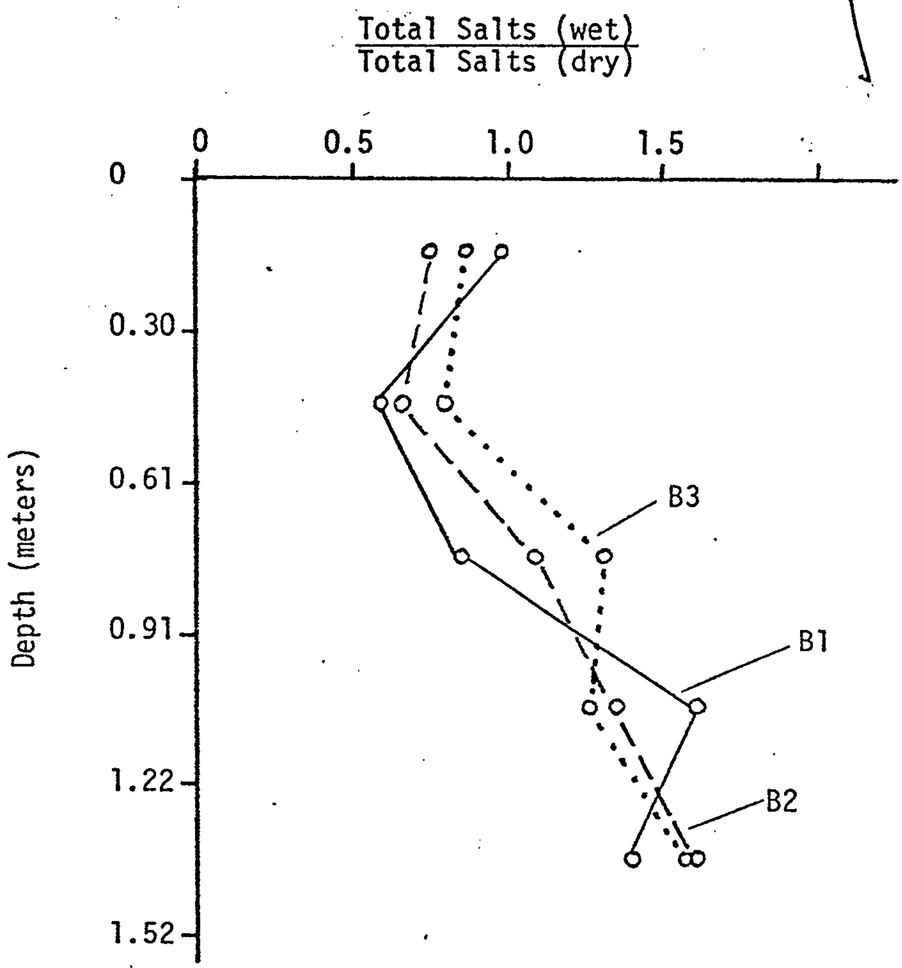


Figure 12. Ratio of total dissolved salts with depth.

APPENDIX

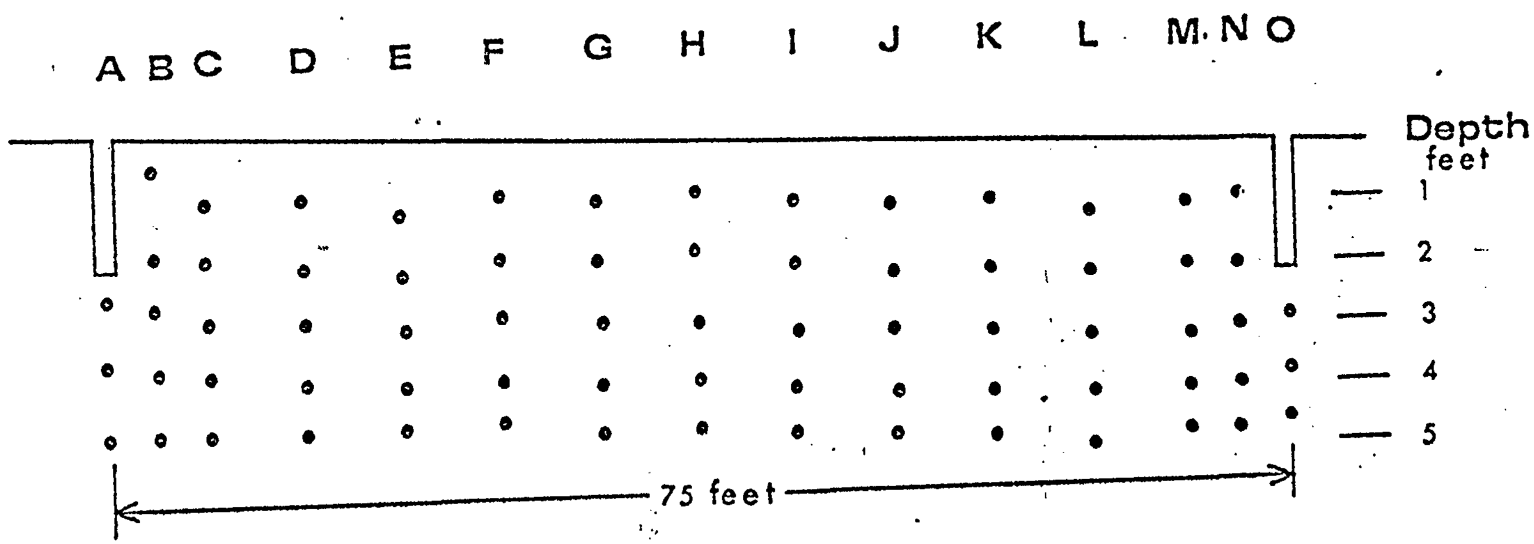


FIGURE 24. GRID SYSTEM OF PIEZOMETERS- RINDGE TRACT.

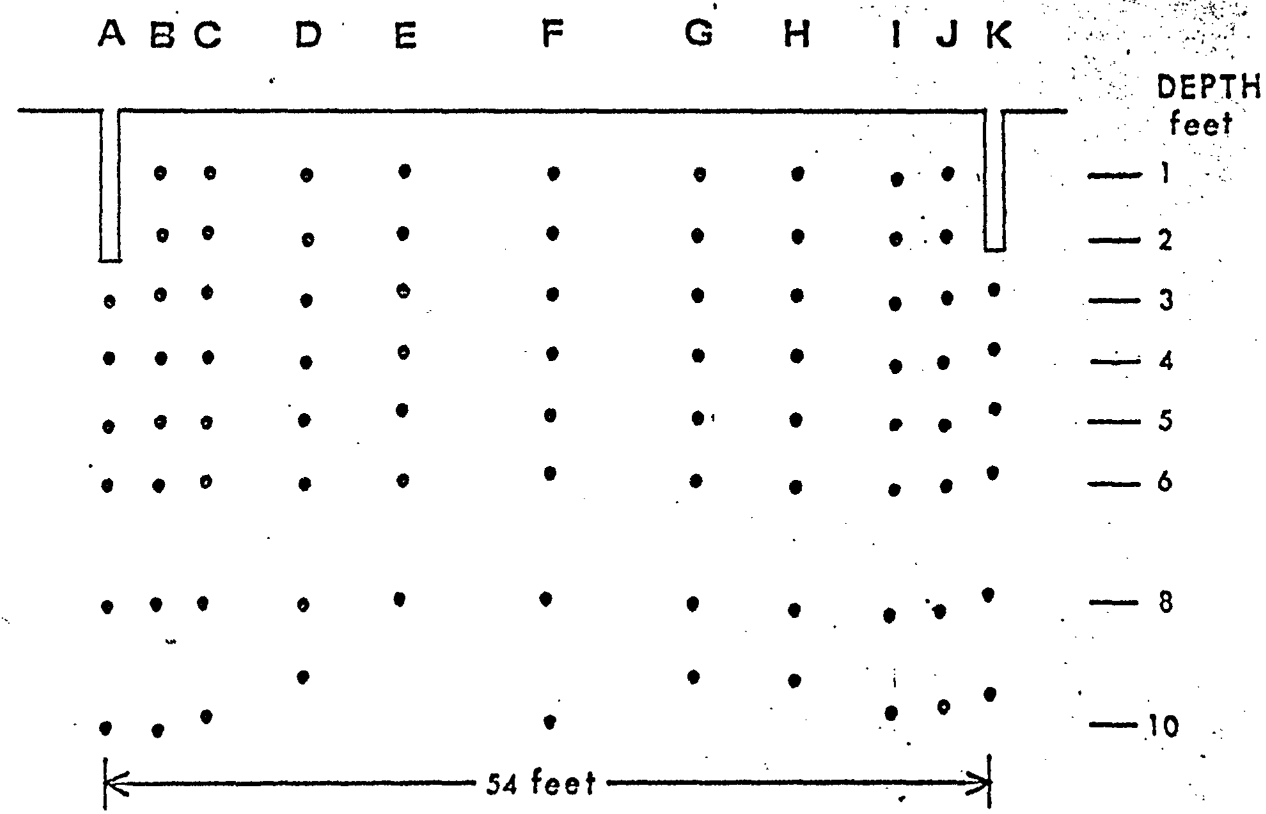


FIGURE 25. GRID SYSTEM OF PIEZOMETERS- BOULDIN ISLAND





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~~[illegible] reports~~ Hanson & Carlton UCD Reports

1. Empire Tract

upward flow of ground water

2. [illegible] Carlton 1975

upward gw flow

3. Upward flow on MacDonald

quality increases w/ depth

[illegible]

quality of gw usually worse than SW

4. upward flow on Ridge

5. Boulder - upward flow,

6. 7. subsurface avg.

8. EC w/ depth, Empire

9. Boulder, SO4 source

10. EC 10-20' range

Terminous, Ridge

11. Upward flow on Empire

12. [illegible]

and CV

~~6/15/87~~
~~4/3/98~~

~~6/18/85~~
~~4/27/98~~

P3 ✓
~~P5~~ ✓
~~P1~~
M3 ✓

$K_V \simeq .01 \frac{cm}{s}$
grad $\simeq .1$
$v_v \simeq 1300$ ft/yr

If assume $\frac{dH}{dx} \simeq .003$

& $K_H = 2.17 \times 10^{-3}$ cm/s

& $\theta = .8$

$$v = \frac{.003 \times 2.17 \times 10^{-3} \text{ cm/s}}{.8} \times \frac{60 s}{m} \times \frac{60 m}{hr} \times \frac{24 hr}{d} \times \frac{365 d}{y}$$

$= 164.2$ cm/yr
$\simeq 5.4$ ft/yr

Table 6. Properties of soils at Empire site.

| Depth (inches) | Number of Samples (n) | Mean | Coefficient of Variation (CV) |
|---|---|---|---|
| | (a) Bulk density ($gm/cm^3$) | | |
| 6 | 4 | 0.66 | 3.2 |
| 12 | 3 | 0.41 | 20.8 |
| 18 | 7 | 0.37 | 40.1 |
| 24 | 7 | 0.38 | 13.8 |
| 30 | 4 | 0.36 | 5.1 |
| 38 (mineral) | 1 | 1.62 | -- |
| | (b) Percent organic matter content | | |
| 6 | 4 | 39.9 | 1.8 |
| 12 | 3 | 61.5 | 28.8 |
| 18 | 3 | 82.3 | 9.3 |
| 24 | 3 | 30.6 | 27.1 |
| | (c) Porosity | | |
| 6 | 4 | 0.69 | 2.0 |
| 12 | 3 | 0.78 | 4.2 |
| 18 | 7 | 0.81 | 4.7 |
| 24 | 7 | 0.83 | 3.2 |
| 30 | 4 | 0.85 | 1.0 |
| 38 (mineral) | 1 | 0.38 | -- |
| | (d) Horizontal hydraulic conductivity (cm/sec) | | |
| 6 | 5 | 0.026 | 67.6 |
| 12 | 4 | 0.011 | 56.6 |
| 18 | 4 | 0.0060 | 110.7 |
| 24 | 6 | 0.0044 | 88.9 |
| 30 | 3 | 0.000064 | 54.0 |
| | (e) Vertical hydraulic conductivity (cm/sec) | | |
| 6 | 6 | 0.027 | 26.6 |
| 12 | 2 | 0.0060 | 2.0 |
| 18 | 10 | 0.012 | 105.9 |
| 24 | 6 | 0.0030 | 56.26 |
| 30 | 4 | 0.0027 | 35.50 |

geom mean of means $= 2.17 \cdot 10^{-3}$

.01

Table 7. Ratio of horizontal to vertical hydraulic conductivity.

| Depth (inches) | $K_H/K_V$ |
|---|---|
| **(a) Rindge Tract** | |
| 18 | 0.16 |
| 24 | 0.29 |
| 30 | 0.03 |
| 36 | 0.04 |
| 48 | 0.11 |
| **(b) Empire Tract** | |
| 6 | 0.97 |
| 12 | 1.75 |
| 18 | 0.51 |
| 24 | 1.47 |
| 30 | 0.02 |
| **(c) Bouldin Island** | |
| 6 | 1.41 |
| 12 | 0.83 |
| 18 | 0.41 |
| 24 | 0.38 |
| 30 | 0.04 |
| 36 | 0.06 |
| 42 | -- |

Table 8. Comparison of "wet" versus "dry" methods of soil sample preparation from a sampling site on Bouldin Island (hole number B-1).

| Depth Interval (feet) | SP (dry) | $EC_e$ (dry) | ① SP×ECe | SP (wet) | $EC_e$ (wet) | ② EC×SP | ①/② |
|---|---|---|---|---|---|---|---|
| 0-1 | 136.2 | 1.73 | 2.36 | 176.5 | 1.29 | 2.28 | 1.03 |
| 1-2 | 182.5 | 0.92 | 1.68 | ~~195.6~~ | ~~0.50~~ | .98 | 1.71 |
| 2-3 | 173.9 | 1.02 | 1.77 | 330.2 | 0.46 | 1.52 | 1.16 |
| 3-4 | 160.1 | 1.43 | 2.29 | 808.4 | 0.46 | 3.72 | .61 |
| 4-5 | 124.3 | 1.70 | 2.11 | 578.7 | 0.51 | 2.95 | .71 |



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